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COMPARISON OF CURRENT TEST REQUIREMENTS AND THE FIELD ENVIRONMENT FOR HARPOON SEEKER WRA'S

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The HARPOON missile system has a reduced reliability for the ship based platform in relationship to the aircraft and submarine based platforms. One possibility for this is that the environmental qualification tests did not demonstrate the susceptibility of the system to this environment. It was therefore necessary to look at the defined mission profiles, environmental conditions and testing to get an idea of what has been done to date. The process of tailoring the levels to the specific platforms was discussed and recommendations made as to updating the test requirements.

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1.0 Introduction

The HARPOON is an all-weather antishipping missile which can be launched from a number of platforms, including aircraft, ships and submarines [1][1]. After launch, the HARPOON flies a sea-skimming trajectory and has the capability to perform several different terminal maneuvers. Mid-course guidance is provided by an attitude reference assembly, radar altimeter and digital computer. The terminal guidance is accomplished using a frequency-agile active radar. Effective range for the HARPOON is in excess of 50 nautical miles.

The HARPOON weapon system consists of the following major subsystems [1]:

Table 1.1 HARPOON Major Subsystems

1.	Guidance Section
2.	Warhead
3.	Sustainer Section
4.	Control Section
5.	Booster
6.	HARPOON Canister Launcher
7.	Submarine Capsule
8.	Support Subsystem
9.	Command and Launch Subsystem
10.	Missile Test Set

Figure 1-1 shows the missile itself, items 1 to 5 above. A common missile body, including the guidance, warhead, sustainer and control sections, is used for air (AGM-84), ship (RGM-84) and submarine (UGM-84) launch configurations. The addition of the booster and the appropriate wings and fins adapt the system to the various launch platforms. HARPOON design permits adaptation to existing launcher and fire control systems. The missile guidance system is autonomous after launch. Control surfaces include four electro-mechanical driven aluminum control fins mounted on the control section. High speed cruise flight is maintained by a turbojet engine with 600 lbs of thrust. For launch from ships or submarines, a solid rocket booster is used to accelerate the missile to flight velocity.

The missile dimensions and weights are [1]:

[1] [n] Number in bracket refers to references given in Section 6.0.

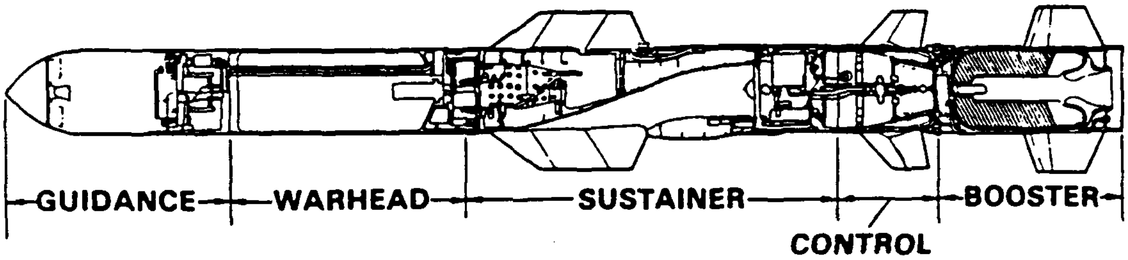


Figure 1-1   Missile Features (Reference 1)

Table 1.2 Basic Dimensions for the HARPOON

Dia⁻ :ter		12.5 in (34.3 cm)
Wing Span		36.0 in (91.4 cm)
Length		
	Airlaunch	151.5 in (389.8 cm)
	Ship/Sublaunch	182.5 in (463.5 cm)
Weight		
	Airlaunch	1144.9 lbs (519.9 kg)
	Ship/Sublaunch	1503.3 lbs (681.9 Kg)

A typical configuration for the air launch is shown in Figure 1-2. It is usually carried as a store under the wing or fuselage and is standard ordnance on both propeller and jet aircraft.

The HARPOON CANISTER Launcher was developed to provide a means of adapting the HARPOON to almost any ship and surface launch application, including land based shore defense systems. Launch configurations consists of a cluster of four canisters on a support structure, Figure 1-3. The missile wings and fins are folded against the missile body to fit within the canister.

The submarine launch HARPOON configuration is the same as for the CANISTER launcher, except that the missile is installed in a buoyant capsule. The capsule is fired from the submarine's torpedo tube and aft-mounted control fins unfold to maintain the required attitude as the missile glides to the surface. Upon broaching the surface, the nose and tail section of the capsule separate automatically and the missile's booster ignites, launching the missile from the capsule centerbody in the same trajectory used in surface launches.

HARPOON was originally designed to meet the environmental design criteria given in XAS-2381A [2]. This document defines environments associated with transportation, storage, handling, at-sea-transfer, captive flight, aircraft carrier, ASROC, Tartar-Terrier, hydrofoil, submarine and free flight conditions.

Based on the mission profiles [3 and 4] and the environmental design criteria [2], tests were developed to show compliance with the requirements. Three levels of testing were specified for the HARPOON including:

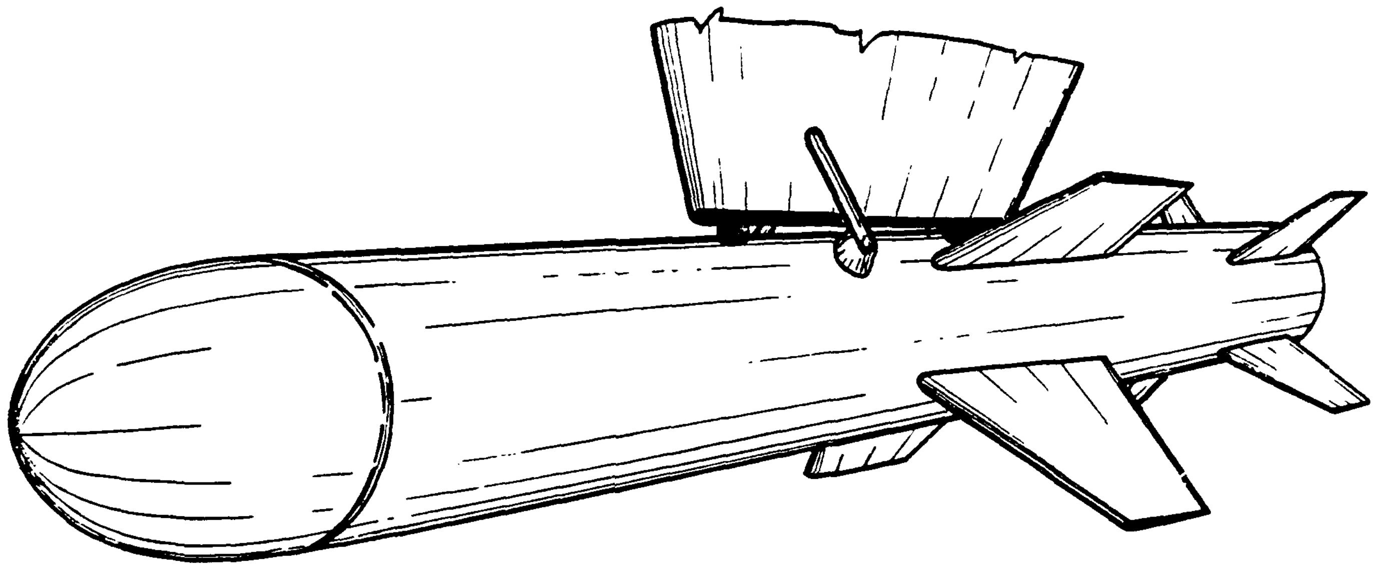


Figure 1-2   Typical Aircraft Configuration

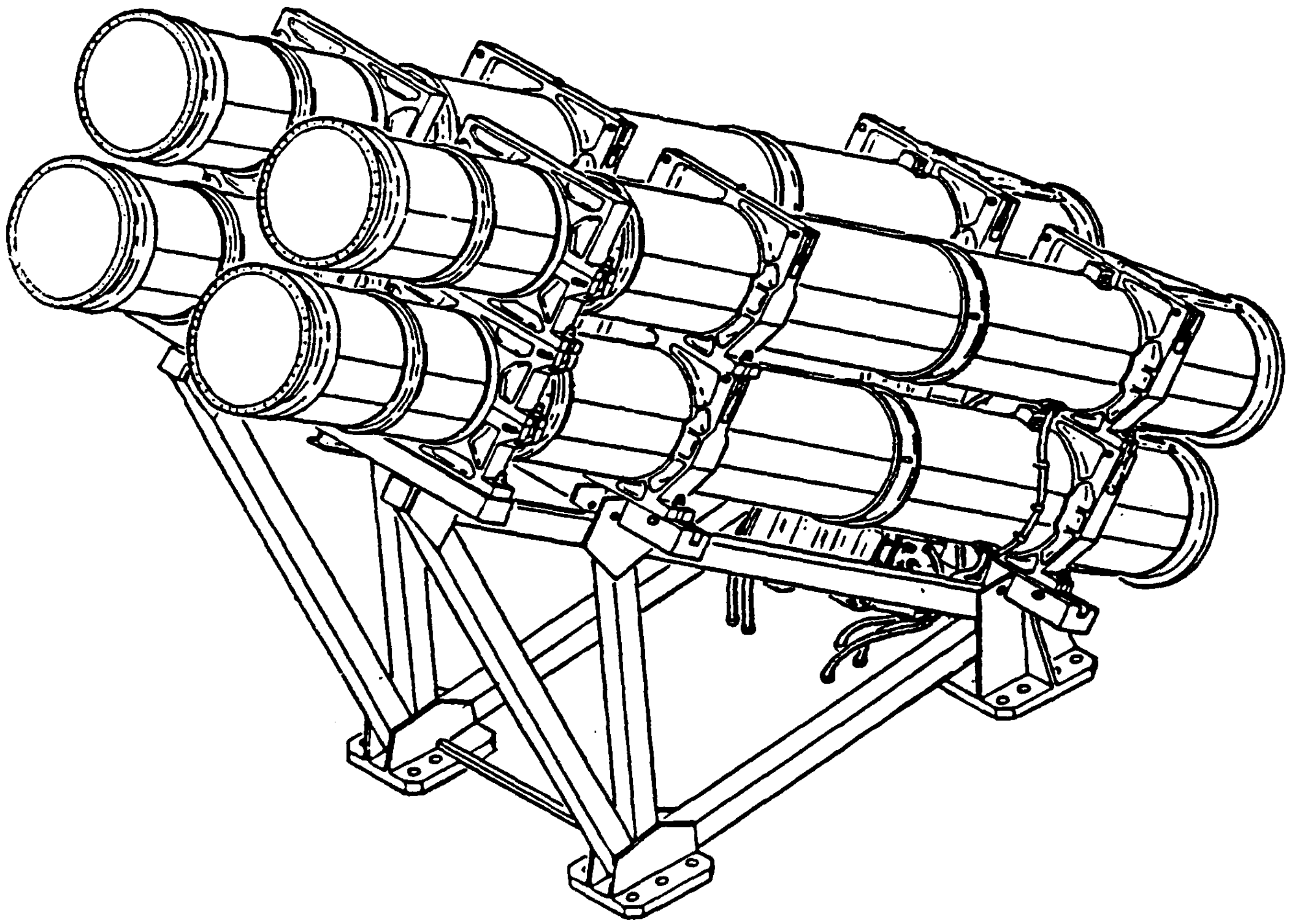


Figure 1-3 Canister Configuration

Table 1.3 Levels of Testing

Qualification/Design Verification Tests	DVT
Pre-Acceptance Screening Tests	PAST
Customer Acceptance Tests	CAT

The DVT tests were designed to demonstrate compliance with the environmental design criteria. The other two tests, performed at reduced levels, are designed to eliminate early failures due to component and manufacturing problems. The missile and its various subsystems were subjected to these types of tests. The environmental conditions simulated in these tests include some of those given in Mil-Std-810D, Table 1.4, a fairly complete listing giving the majority of exposure conditions.

Service history records of the HARPOON weapons system indicated that the ship based systems had a failure rate that was significantly greater than the other platforms. A program was initiated, under the direction of the Pacific Missile Test Center (PMTC), to look at various aspects of the ship platform in an effort to determine the cause for the high failure rate.

The first portion of this program consisted of measurement of the missiles dynamic response during captive carry condition. Instrumented missiles were placed aboard the USS Mississippi and subject to a series of operating conditions, including various engine RPM, maneuvers and gun fire. During the testing the sea states were benign. Results of this captive carry testing are presented in References 5 and 6.

As a follow-on, modal tests were performed on a Launch Support Structure (LSS) onboard the USS Scott [7]. In addition, laboratory tests were performed at PMTC to look at the dynamic response of a single missile inside a canister. The system was subject to a series of vibration test with several different designs for the shoes and studs supporting the missile within the canister [8]. A summary of Southwest Research Institute's (SwRI) participation in all these studies is contained in Reference 9.

A final portion of the program in which SwRI participated was the performance of laboratory vibration tests on a complete canister system on a LSS. This was an attempt to perform Mil-Std-167 [10] testing on the system to demonstrate the feasibility of a new clamp ring isolation pad. It was not possible to complete the sequence of Mil-Std-167 testing due to damage to the trainers, used to simulate two of the four missiles. Modal analysis was performed and results compared favorably with previous data. Results of this testing are contained in Reference 11.

During the course of the overall of this program, directed by PMTC, it was determined that an updated definition of the environmental design criteria [2] was needed. An updated, but classified, version of the environmental design criteria has been developed [12]. To keep the scope of this report unclassified, only references to the original version [2] of this document will be made. Where necessary, the reader may wish to interpolate the data presented in this report with reference to the updated requirements.

Table 1.4 Test Methods in Mil-Std-810D Applicable to HARPOON Weapons System

810D Method	Condition	Applicable Procedures	Comments
500.2	Low Pressure (Altitude)	Operation	
501.2	High Temperature	Storage Operation	Hot or Basic Hot Climatic Categories Ambient Air or Induced Conditions
502.2	Low Temperature	Storage, Operation and Manipulation	Mild Cold, Basic Cold, Cold or Severe Cold Climatic Categories Operational or Induced Conditions
503.2	Temperature Shock	Aircraft Flight Exposure or Engineering Design	Same Categories and Conditions as 501.2 and 502.2
506.2	Rain	Blowing Rain, Drip or Watertightness	
507.2	Humidity	Natural, Induced or Aggravated	Hot-Humid, Constant, or Cyclic Diurnal Categories
509.2	Salt Fog	Aggravated Screening	
510.2	Sand and Dust	Blowing Dust or Blowing Sand	
512.2	Leakage (Immersion)	Basic Leakage	
513.3	Acceleration	Structural or Operational	
514.3	Vibration	Categories 4 - Propeller Aircraft 5 - Jet Aircraft and Tactical Missiles 7A - Assembled External Stores, Jet Aircraft 9 - Shipboard Vibration	Random, Source Dwells, Sinusoidal Excitation Input versus Response-Defined Control Endurance versus Functional Testing Engineering Development Testing Environmental Worthiness Testing Qualification Testing
515.3	Acoustic Noise	Environmental Worthiness, Qualification or Mission Profile	
516.3	Shock	Test Procedures I - Functional Shock VII - Pyrotechnic Shock IX - Catapult Launch/Arrested Landing High Impact/Shipboard Equipment (MIL-S-901)	
519.3	Gunfire Vibration, Aircraft		Combined Broadband and Narrowband Random Excitation
520.0	Temperature, Humidity, Vibration, Altitude	Engineering Development, Flight Operational Support or Qualification	Vibration, Thermal, Humidity, Altitude, and Electrical Stresses
521.0	Icing/Freezing Rain	Glaze Ice	
523.0	Vibro-Acoustic, Temperature		Combined Vibration, Acoustic and Thermal Stresses

The problem was approached using the test tailoring procedures outlined in Mil-Std-810D [13]. The tailoring process was limited to literature review of various data that had been measured for the HARPOON system as well as generic data. Some adaptation of existing data to satisfy current requirements was made. No new test programs or detailed analysis was developed to satisfy the requirements of this phase of the HARPOON program.

Recommendations of how the environmental design criteria should be updated to correspond to current deployment of the weapon systems have been made. With the amount of hardware already in the field, these updated criteria will not have an effect on the reliability of existing hardware. It is not the intention of these recommendations that old hardware be requalified to the updated levels, but that the criteria be applied to future hardware systems or components to insure acceptable reliability levels.

The work was performed for PMTC under a special task for the Nondestructive Testing Information Analysis Center (NTIAC). Each of the three levels of testing: DVT, PAST, and CAT, are nondestructive methods of demonstrating the compliance of the hardware components. The project was aimed at recommending changes to the testing to provide a more realistic test level, and in turn improve the overall reliability of the system.

2.0 Objective

There were three primary objectives for this project:

1. Determine the current test requirements in conjunction with the seeker WRA's. At the same time, determine the nature of the tests performed on the seeker WRA's and the results.

2. Define updated field environments for the platforms.

3. Recommend changes to the current test requirements to reflect updated field environments.

As noted earlier, this work was performed by SwRI for PMTC. A minor portion of the work was subcontracted to ORI, Inc., based on their knowledge of the HARPOON system. This included retrieval of information for the HARPOON library [14]. This project was an overview of the problem and should not be considered a definitive document. This is due to the fact that the statement of work was modified during the project to cover other critical items. In addition, there were time and cost constraints.

The primary interest of the project was a study of the CANISTER version of the HARPOON system since it had the highest failure rate. Results for the other systems are based solely on published information and data.

3.0 Conclusions

At the initiation of this program the primary objective was to look at current test levels in relationship to present knowledge of the service environments for the HARPOON weapons system and to develop recommendations as to changes to the test requirements that may be required to insure acceptable reliability of the system. As the program progressed the thrust began to change. This was due primarily to the nature of information available. It was difficult to determine the extent of testing that has been performed on the HARPOON weapons system, and the results therefrom, both at the system and at the Weapons Replaceable Assemblies (WRA) level. The test levels that the current system has successfully withstood are not possible to define in any detail. Therefore, the need for additional test tailoring became more difficult to justify. That is not to say that tailoring is not necessary, but that it can only be justified on the basis of comparison of levels rather than demonstrated capabilities and reliabilities of the system.

During the testing performed on the system a number of anomalies were observed as a result of several environmental conditions. The environmental conditions under which anomalies occurred included but are not limited to high temperature, restrained firing and shipboard vibration. Additional anomalies were recorded but it was not possible to define the environmental condition(s) that caused them due to limited data on the results of some of the testing.

Similar results were noted for tests done at the WRA level. In this case failures were noted as a result of high temperature, humidity and vibration testing. It appears that the various WRA's were not subject to the range of testing that the system was.

The majority of the environments in XAS-2381A [2] are representative of the environments that the HARPOON will be subjected to. For these environments it is important to insure that they were then transmitted into requirements in the test plans for the various levels of testing. There are several environmental conditions defined in XAS-2381A which do not accurately represent all the environments that the HARPOON will experience in-service. Since it was initially published in 1978, knowledge of the service environment and the platforms on which it is based have progressed. Implementation of other weapons systems, such as the high velocity round, and modification of current platforms such as inclusion of the CANISTER for example, have significantly affected the environments. It is important to note that the XAS-2381B does exist but it was not reviewed in this report due to limited access.

The Life Cycle Environment Profile [3 and 4], i.e. the history of events and associated environmental conditions for an item from its release from manufacturing to its retirement from use for the HARPOON, needs to be updated. When considering a life cycle, it is not appropriate to look at a missile as a whole. Because of the interchangeability of the major sections, a given missile may be made up of different major sections during it lifetime. Because of this it is appropriate to define a life cycle in terms of a major section or a WRA. A life cycle of a major section can include exposure to environmental conditions associated with all of the platforms. Because of the questions concerning the number of cycle in the current mission profile it was not possible to develop test times for vibration based on the test levels and the service levels and times.

4.0 Recommendations

The recommendations are divided into two basic groups. The first are those where sufficient information exist to make concrete recommendations as to changes in either levels or duration of testing. The second group is for additional work that is required prior to making judgements on potential problem areas.

It is appropriate to update the mission profiles to the current usage. After this is done it will be possible to make a better judgement on the adequacy of the levels for various environmental conditions. Continued updating of the reliability of the various systems will also provide useful information. In addition to general reliability numbers, it is also necessary to track failures and define their cause. In this way it may be possible to isolate weak components and/or damaging environmental conditions. This will assist in defining the appropriate fixes and testing required to increase reliability.

It is not apparent from the literature review that the environmental criteria defined in XAS-2381A have been fully implemented for the missile and WRA's. A further review of the entire scope of the testing performed is required. This includes tracking the XAS-2381A requirements to the test plans for the missile in its various configurations as well as all of the WRA's testing. Once the appropriate test plans have been identified, it will be necessary to determine if the testing was actually performed with satisfactory results.

One area that needs to be changed is the high temperature limits. As a result of testing and information on induced conditions resulting from high temperature and solar radiation, a level of 160° F is recommended. It is recommended that future testing for high temperature extremes be defined by the induced conditions for the hot climatic criteria as defined in Mil-Std-810D. This is a twenty-four hour cycle designed to represent expected conditions during a day. It is recommended that at least seven cycles of this profile be performed. During this testing the missile or WRA should be functionally checked while at the temperature extremes to insure operability. This condition would simulate the requirement to fire the missile from a CANISTER configuration during a hot day.

It is apparent that during the testing to date, anomalies have been induced by humidity. It was not possible to determine the extent of the anomalies or what corrective action was taken to prevent their reoccurrence. It is therefore recommended that some additional work be performed in determine the nature of the humidity testing performed on the missile and WRA, and the results of the testing. Concurrently, the implementation of any corrective action needs to be tracked. Based on these findings, it will be possible to determine if additional humidity testing needs to be performed on any of the WRA's. Because of the nature of the use of the HARPOON in-service, it is recommended that humidity testing of components and the systems be based on the aggravated conditions defined in Mil-Std-810D. It is recommended that when testing is required a minimum of 10 twenty-four hour cycles be performed in accordance with Figure 507.2-3 [13]. Again, functionality of the missile and/or WRA needs to be checked during the testing.

The reliability of the CANISTER system, when subjected to the long duration exposure onboard ship, is low. It is not apparent from the data whether the failures are the result of temperature, humidity or vibration problems or a combination of these. The adequate simulation of the vibration environment is still to be resolved. A first step would be to subject four missiles in CANISTERS on a LSS to the random vibration tests given in Figure 5-47. The duration of the testing needs to be defined in relationship to current mission profile data and accelerated testing techniques. The current system has never been qualified to any level since the Mil-Std-167 testing performed resulted in anomalies. The random testing is recommended in lieu of the sine testing since it more closely represents in-service conditions.

Another consideration concerning the CANISTER system is the level of vibration testing preformed on the WRA's. From data it is apparent that there is amplification between the levels present at the feet of the LSS and the WRA locations. Taking the random vibration levels defined at the deck of the ship and modifying them by the appropriate transfer will define the appropriate levels. These may be below those utilized for the captive carry on the aircraft, but the duration of that testing may not be sufficient to simulate the long duration exposure at sea. Based on the updated mission profiles it will be possible to make these comparisons.

It is also not apparent from the data that the functional vibration levels for captive carry onboard an aircraft are adequate. Close review shows that data measured on the HARPOON by McDonnell Douglas is lower than the defined test levels. More recent data on a wide variety of aircraft shows that the levels may be low. It will be necessary to resolve these differences.

Based on the results of the USS Mississippi testing, it is appropriate to update the shock loading due to gunfire for the ship based platform. This means either increasing the amplitude of the pressure pulse or modification of the required shock spectra. It is not the intent to just increase the level of the enveloping half sine wave pulse for the WRA's. The shock time histories are not single pulses and contain energy over a significant time. It is therefore recommended that the shock test pulses contain multiple peaks due to response of the overall system rather than the single pulse indicated.

It is not the intent of these recommendations to require requalification of the HARPOON system. The intent is to adapt the updated requirements to new procurement of replacement components. It is appropriate to apply this information to other weapons systems where these systems can be shown to be subjected to similar environmental conditions and have similar platform characteristics.

5.0 Discussion

5.1 Test Tailoring

Service history records of the HARPOON weapons system have indicated that the reliability of the ship based missile is lower than that associated with other platforms [15]. Because of the higher level of failure, a project was initiated to define more accurately the service environments and/or structural differences between the platforms. As part of this project, it is necessary to compare the environmental qualification test levels currently in use, the environmental design criteria, and the environments measured or expected in the field.

The approach is based on the concept of test tailoring as defined in Mil-Std-801D [13]. Tailoring is defined as "The process of choosing or altering test procedures, conditions, values, tolerances, measures of failure, etc., to simulate or exaggerate the effects of one or more forcing functions to which an item will be subjected during its life cycle." The objectives and tasks required to perform the tailoring process include [Ref. 13 page 4]:

> "The objective of tailoring it to assure that military equipment is designed and tested for resistance to the environmental stresses it will encounter during its life cycle. ... To assure such consideration, environmental management plans shall be formulated that require the following engineering tasks: determination of life cycle environmental conditions; establishment of environmental design and test requirements, including a test plan; and collection and analysis of field data for verification of environmental design and test criteria. Proper attention to each of these tasks insures that the correct environments are identified for test, that engineering development as well as qualification tests are phased properly into the item's acquisition program, that environmental test conditions are traceable to life cycle conditions realistically encountered, and that testing is appropriate for the item application."

Documentation required under the tailoring process include [13]:

a) Environmental Management Plan
b) Life Cycle Environmental Profile
c) Environmental Design Criteria
d) Test Plan and
e) Operational Environmental Verification Plan.

Under normal conditions, all of these documents are generated during the early stages of the development of a weapons system. For the HARPOON system, the life cycle environmental profile is contained in Reference 4, while the environmental design criteria refers to Reference 2. Unique test plans were generated for the system as a whole, as well as the component level. Recent work [15] has lead to the development of recommendations for a program to satisfy portions of the operational environmental verification plan. The author has not kept track of the implementation of the program proposed in this reference. From the documentation received at SwRI, it is not apparent where the information required for item a) is contained.

As a weapons system is introduced into service and data is obtained on the field environments and the reliability of the system, it is necessary to cycle this information back into the other documents. The intent of this project is to provide recommendations where the environmental design criteria and test plans need to be updated.

Figure 5.1 gives a general outline for the tailoring process prescribed in Mil-Std-810D. In this program we will consider aspects of the Natural Environments Characteristics, Item Platform Characteristics, Platform Environments and Test Procedures. These four areas will provide sufficient information to answer some important questions relative to qualification tests, environmental design criteria and the true environment.

If modifications to the HARPOON system are subsequently considered, it will also be necessary to incorporate the aspects of the Item Requirements Documents and the Design Requirements. This is not a part of this project.

5.2 Current Information and Procedures

Information presented in this report is based on a review of available literature. No attempt was made to develop any new information. The available literature included the ORI library for the HARPOON [14], published literature and additional information supplied by PMTC.

For this project three platforms for deployment were considered:

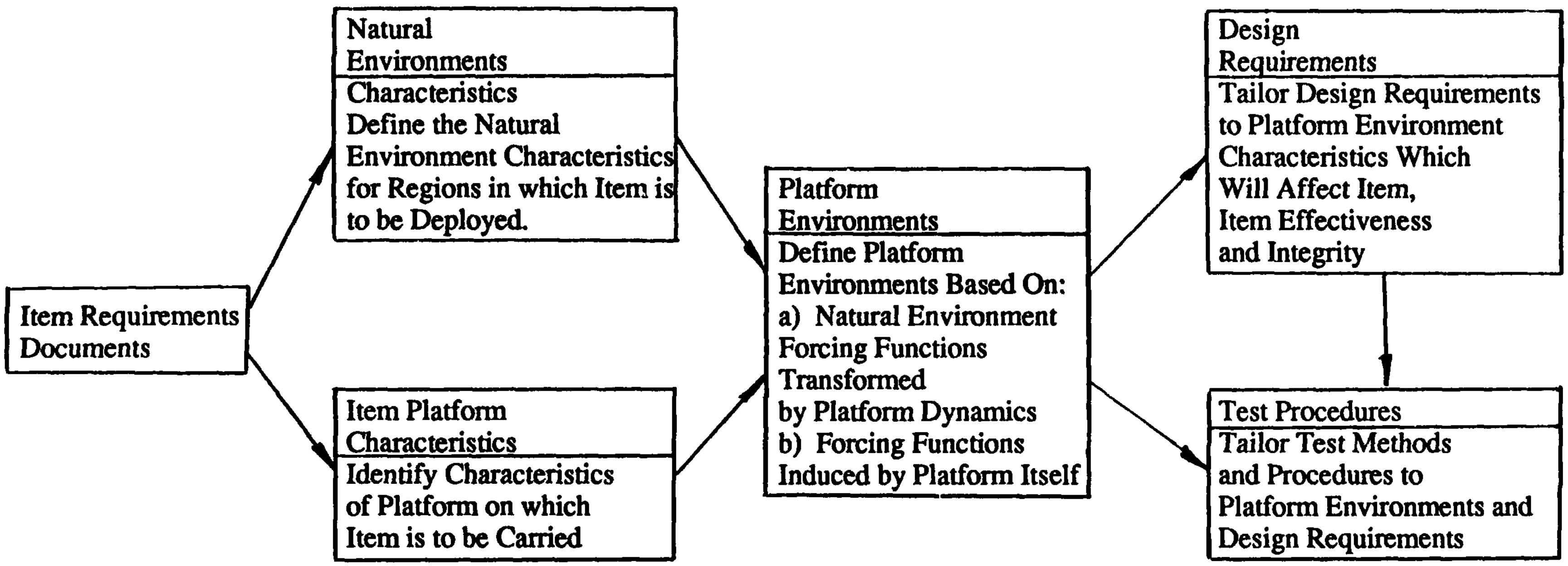


Figure 5-1 Environmental Tailoring Process (From Reference 13)

Table 5.1 HARPOON Platforms

Air Based		
	AIRLAUNCH	AGM-84A/C-1
Ship Based		
	ASROC	RGM-84A/C-1
	TARTAR	RGM-84A/C-2
	CANISTER	
	Lightweight	RGM-84A-3
	Grade-B	RGM-84A/C-4
	Thickwalled	RGM-?????
Submarine Based		
	CAPSULE	UGM-84A/C-1

Each of the platforms have differences associated with the support conditions and enclosure for the captive carry portion of the life cycle. These conditions have a significant effect on both environmental extremes and platform induced responses.

Each of these three platforms have a basic missile and additional equipment required to modify it for the specific platform. The basic missile is made up of four major sections: control, sustainer, warhead and guidance. For certain platforms, a fifth major section, the solid fuel booster, is attached to the control section. For this project, we were interested in defining the environments for weapon replaceable assemblies (WRA's) in only the guidance section, including: Seeker, Probe/Crush Sensor, Electronic Equipment, Midcourse Guidance Unit (MGU), Digital Computer with Power Supply, Altitude Reference Assembly (ARA), Radar Seeker and Altimeter with Power Converter.

For the air based system, the environmental conditions during captive carry are influenced by the flight envelope of the various aircraft. The dynamic characteristics are influenced by a number of parameters, including: pylon configuration, wing structure dynamic characteristics, engine location, and type and effect of other armaments. The HARPOON is carried on the following US aircraft:

P-3 Orion Antisubmarine Warfare (ASW) Patrol

S-3 Viking ASW Patrol

A-6 Intruder Attack

A-7 Cosair Attack

F/A-18 Attack

B-52 Bomber

In addition, foreign nations utilize the missile on several other aircraft types. Each of the aircraft will induce different environments on the missile. The location of the missile, inboard vs outboard wing pylons or fuselage pylons, will effect its dynamic response. A primary effect is the dynamic compliance of the pylon and wing structure. This will influence the low frequency vibration levels to which the missile is exposed. The location of the missile, in relationship to the engines, will effect the level of structural and airborne vibration. The flight envelope of the aircraft will have an influence on the thermal and vibration levels based on the ceiling and maximum dynamic pressure (q).

The three ship based platforms: ASROC, TARTAR and CANISTER, are all placed on launchers for service. The ASROC and CANISTER missiles are enclosed in a launcher throughout its captive carry life. In the ASROC configuration, they are located in an eight cell system that can vary its orientation prior to firing. The CANISTER system is installed in a four cell system that is fixed at the base. Since these launchers are deck mounted, they will be subject to significant temperature variations and moisture exposure. For the TARTAR configuration, the missile is stored below deck in a magazine prior to loading on the launcher. In all cases, the dynamic characteristics of the launcher structure will have a significant influence on the response of the missile during captive carry. In addition, the location of the launcher on the deck and the characteristics of the ships propulsion and auxiliary machinery will influence long term reliability.

Platforms have been adapted for the following classes of ships:

PHM Patrol Hydrofoils

FF-1052 Class Frigates

FFG-7 Guided Missile Frigates

DD and DDG Class Destroyers

CG and CGN Class Guided Missile Cruisers

BB Battleships.

Compared to the other environments, the captive carry portion of the submarine based system is benign. This missile is stored on racks inside the capsule prior to loading in the torpedo tubes. The controlled environment and limited dynamic response are the primary reason that this configuration has high reliability. Because of this and a lack of published literature, little information will be presented for this platform in this report.

5.2.1 System Reliability

From information supplied in Reference 16, the time in the fleet distribution for the ship and submarine based systems is given in Figure 5-2 and Table 5.2. This information is based on the number of missiles returned to NWS's between 1980 and 1983. At the time this information was compiled, the total number of returned missiles for the CANISTER configuration was the highest, 527.

The time in the fleet data was transformed to cumulative distribution data, Figure 5-3, by dividing the number of missiles in each block by the total number of missiles for a given configuration. There are a number of underlying facts that need to be considered when reviewing the data. Among them are the defined mission length for each system which may vary in both definition and practice. In addition, the time between BIT's will have some effect on the time at which a missile is returned for repairs. The shape of the cumulative distribution functions can, in all cases, be fit to a normal distribution with appropriate mean and standard deviation. Data for the total HARPOON system, i.e. the sum of all configurations, is given in Figure 5-4. The fit is reasonable because of the large data sample. Comparison of the cumulative distribution for the various systems in a normal distribution are not as good as that for the entire database.

Compared to all the platforms, the TARTAR and CAPSULE has a higher average time in the fleet and the CANISTER and ASROC have lower averages. The submarine based system, CAPSULE, time in the fleet is 26.5 months. This is to be expected considering the controlled environment onboard the submarine. It also has the highest standard deviation assuming a normal distribution. Of the returned missiles, the CANISTER configuration shows the highest overall failure rate. The failures are defined in terms of the factors that may have caused them as identified by the built in test (BIT). Reference 17 gives these failure percentages for the period 1980 to 1983, Figure 5-5 and Table 5.3.

The number of failures during transportation is greatest for the two CANISTER configurations. This could be due to the fact that these configurations are shipped inside the canisters. It is possible that the shipping containers, MK 631, used for these configurations are not as effective at isolating the missile from the transportation induced environments: temperature, humidity, vibration and shock.

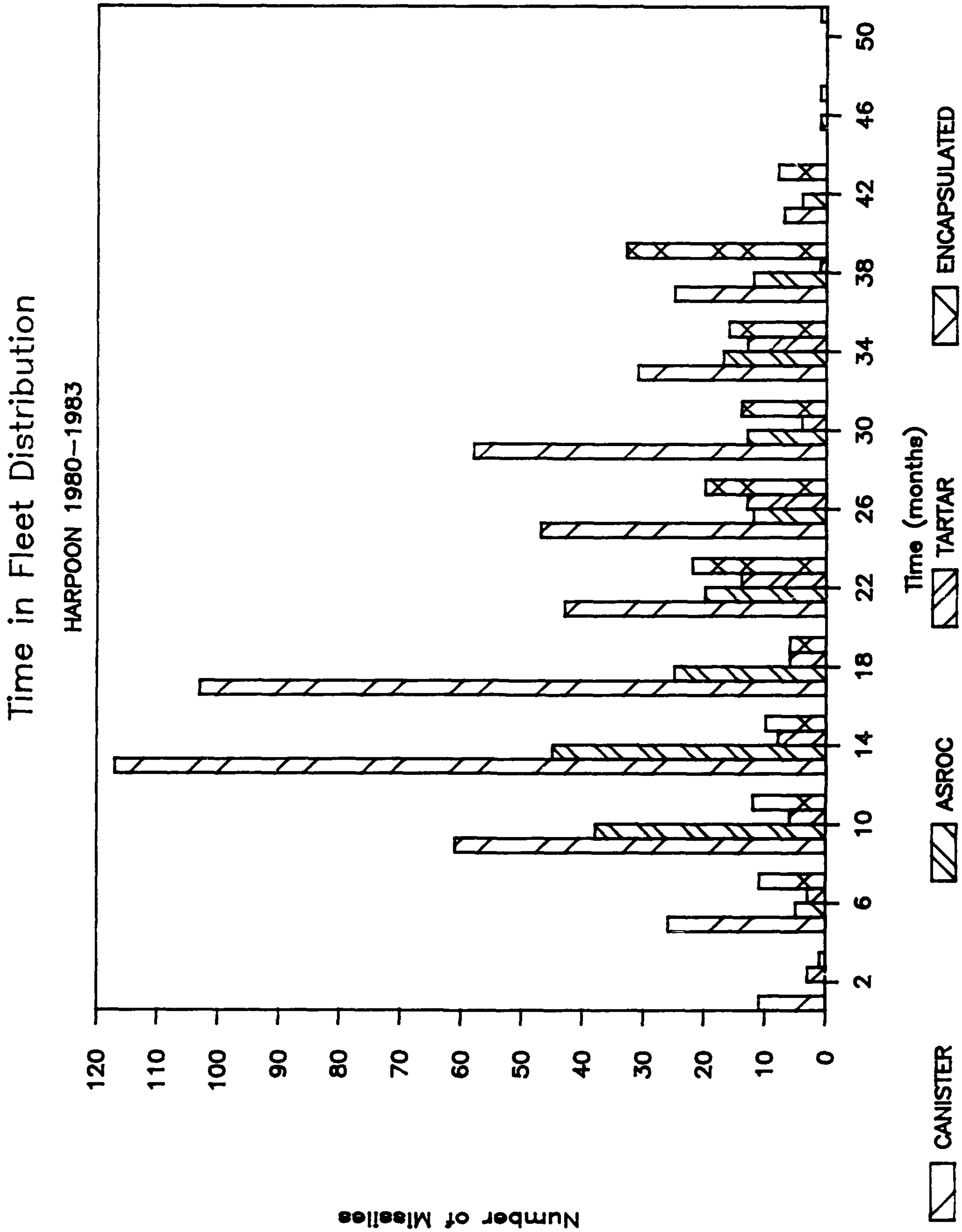


Figure 5-2 Time in Fleet for Ship and Submarine Based System

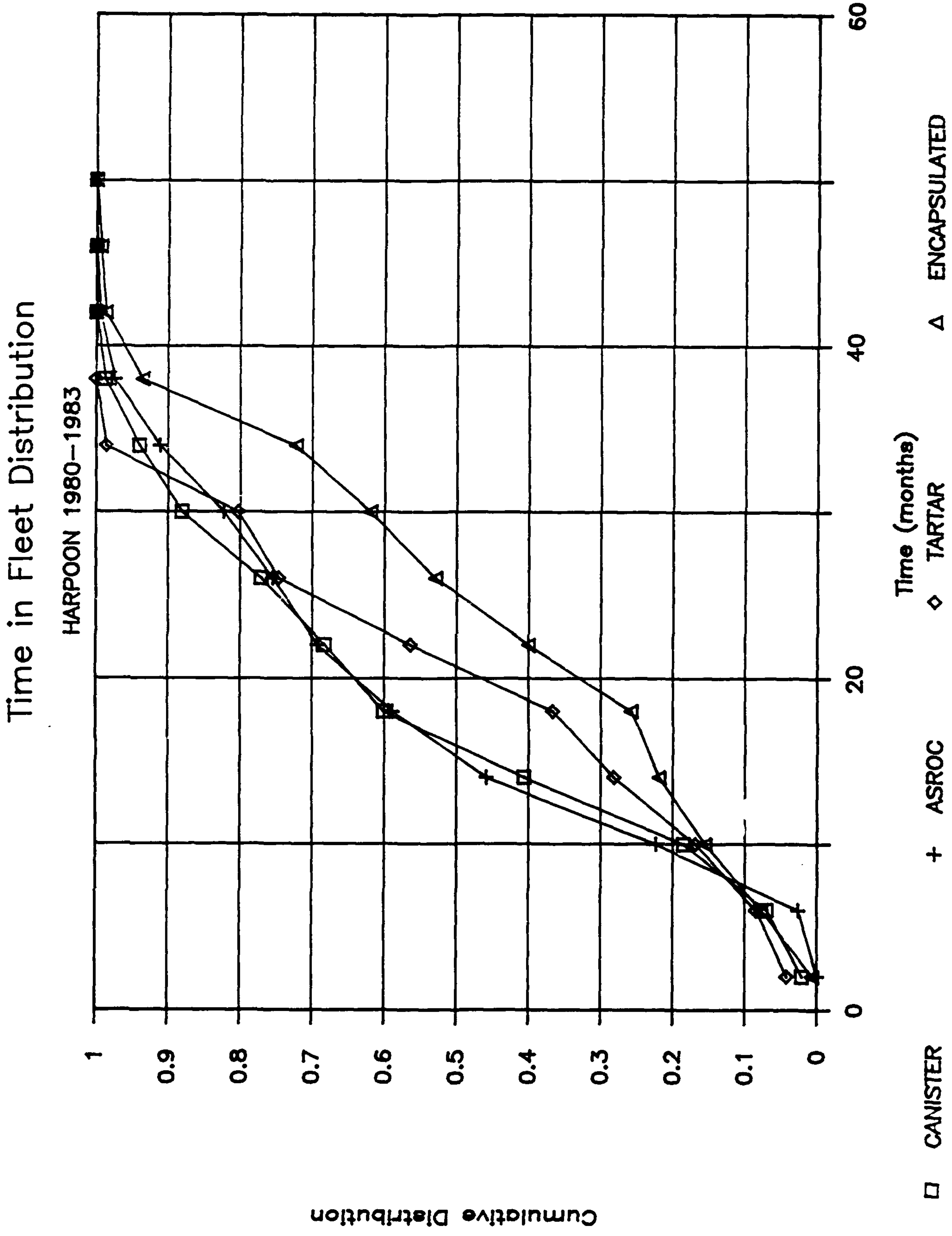


Figure 5-3 Cumulative Distribution for Ship and Submarine Based System

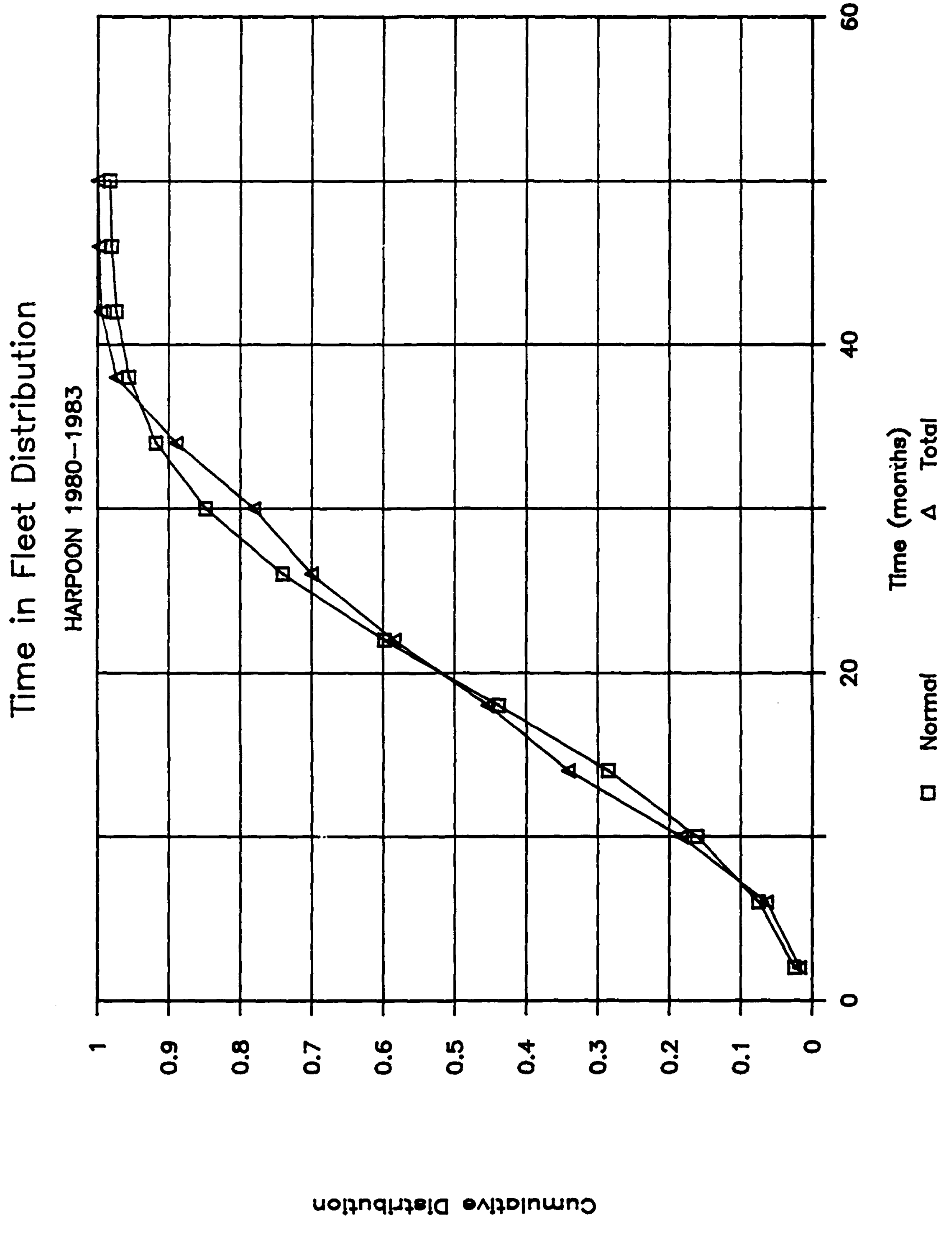


Figure 5-4 Cumulative Distribution for Total Ship and Submarine Data vs Normal Distribution

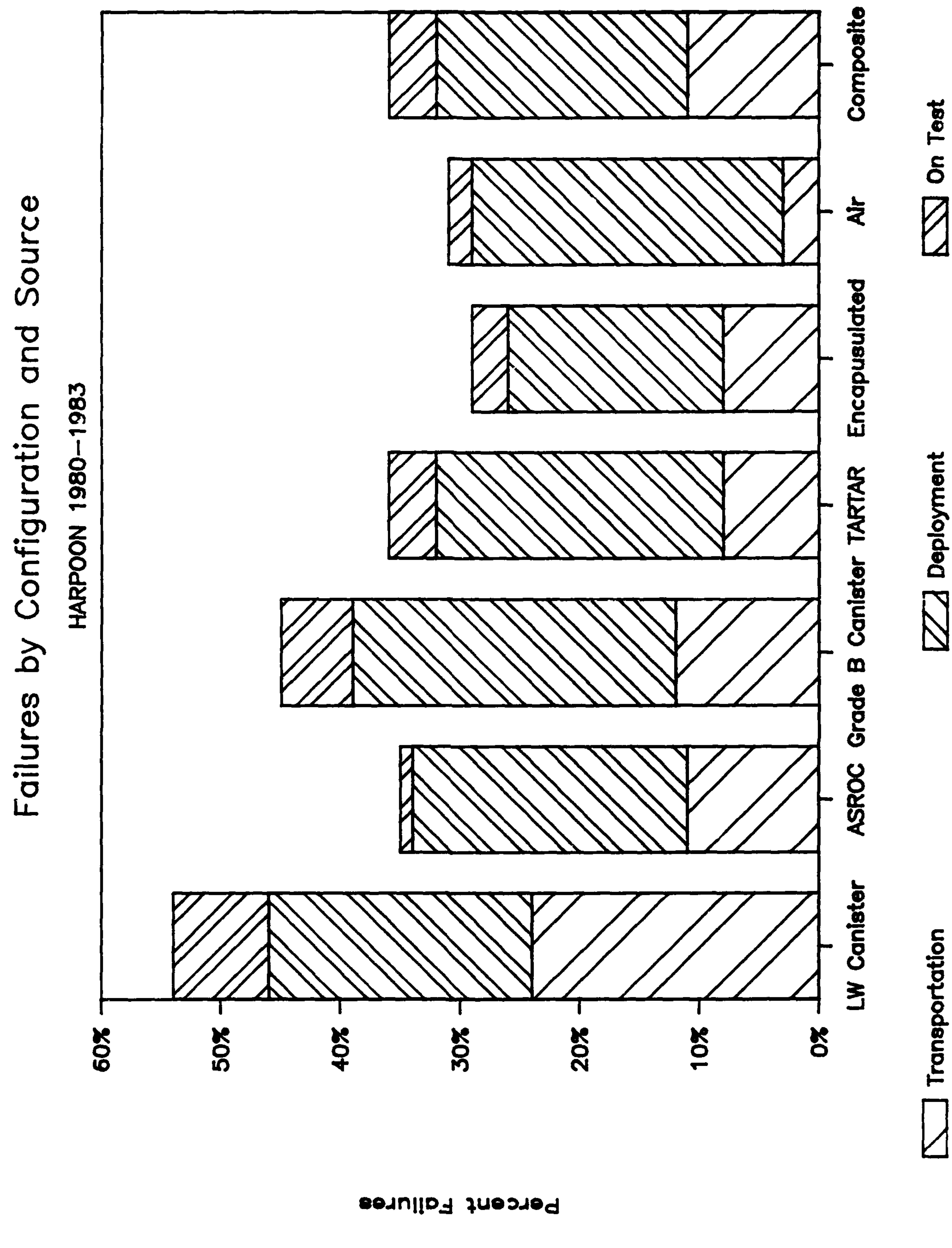


Figure 5-5 Failures by Configuration

Table 5.2 Time in the Fleet by Configuration

Configuration	Number of Missiles Returned	Average Time In Fleet Months	Standard Deviation Months
CANISTER	527	19.8	9.18
ASROC	192	20.2	9.72
TARTAR	71	21.8	9.22
CAPSULE	155	26.5	11.14
Total	945	21.1	9.93

Table 5.3 Failure Percent by Configuration

Configuration	Percent Failing			
	Transportation	Deployment	On Test	Overall
LW CANISTER	24	22	8	54
Grade-B CANISTER	12	27	6	45
ASROC	11	23	1	35
TARTAR	8	24	4	36
CAPSULE	8	18	3	29
AIR	3	26	4	31
COMPOSITE	12	21	4	37

During deployment, the largest failures are for the Grade-B CANISTER and the air configurations. The high failure rate for the air conditions may be a result of the high level of the captive carry environments. For the CANISTER configuration, it is most likely a combination of the levels of the environment and their duration that cause failure. This is reflected in the fact that the LW CANISTER data shows a lower failure rate than the Grade-B, although the environmental levels are higher. The CAPSULE shows the lowest failure during deployment due to the benign environment aboard the submarines.

The overall levels of failure during test are low. In addition to the BIT failures, data based on firing results, after pilot production, indicate that the CANISTER configuration has a lower reliability, Table 5.4 [16].

Table 5.4 HARPOON System Reliability

Configuration	Reliability
CANISTER	0.81
Other Ship Launch	0.96
All Other than CANISTER	0.95

5.2.2 Life Cycle Environmental Profile

One of the documents required for application of the tailoring process is the Life Cycle Environment Profile, i.e. the history of events and associated environmental conditions for an item from its release from manufacturing to its retirement from use. It covers the Natural Environment, Item Platform Characteristics and Platform Environments defined above and should included conditions associated with:

a) Shipping/Transportation
Road, Rail, Air and Ship

b) Storage/Logistic Supply
Handling, Logistic Transport and Storage (Open and Sheltered)

c) Mission/Sortie Use
Deployment, Use and Delivery to Target

Items a) and b) are not part of the current program, and therefore, will not be considered in this report. However, they must be considered when implementing the recommendations made herein. This fact has been stressed a number of times including [16]:

> "The Canister missile shows a higher failure rate while on test and in free flight where environments are the same as other missile types.
>
> -- This is indicative that degradations occurring earlier can show up in later mission phases. Thus ---
>
> -- Higher failure rates in transportation could be due to degradation during exposure to ship environments.

-- Higher failure rates aboard ship could be due to degradation during exposure to transportation environments.

-- etc.

It is therefore necessary to examine all mission phases (transportation, handling, aboard ship, etc.) to determine where degradation takes place."

Only information associated with item c) will be considered in this project when comparing field environments to design criteria and current test levels.

References 3 and 4 give the mission profiles for a number of HARPOON configurations. The mission profile data is presented first in terms of a flow diagram showing the interrelationship between various phases of the mission profile. These include time in the container, transportation, storage, handling and captive flight. Some details as to specific handling equipment, such as AERO-51 Trailers, and MK 45 load trucks, are included on these flow diagrams. The second portion of the mission profile data defines in more detail the environmental conditions, number of cycles and their duration. The environmental conditions include vibration level, peak shock, temperature range, altitude and peak over-pressure as a function of the phase. For each phase, a number of cycles is given, as well as the duration of the cycle. This allows the total exposure period for a given set of environmental conditions to be determined. In addition, the times at which BITs are performed are given.

It is not apparent if these profiles have been updated since they were defined in 1977. From discussions of field service data, it appears that the actual mission profiles have been modified in relation to those defined below. This information will have to be incorporated into the process to insure an accurate representation of field conditions. For this project, it will be assumed that the mission profiles are as defined below. The cycle period of any one missile is defined as the time from all-up-round MSTS testing to the time when maintenance is due. A particular missile or component may undergo a number of cycles.

As noted earlier, the primary concern of this project is a definition of the service environments during captive carry conditions. Where appropriate, some discussion will be made concerning the level of storage and transportation environments. Each of the three types of platforms; aircraft, ship and submarine, will be discussed. The environments that the missile will see during free flight will be discussed in Section 5.4. These are the only three portions of the life cycle that will be considered in this project.

5.2.2.1 Air Based Platforms

The air based platform can be divided into two basic configurations. The first is captive carry aboard the multiengine turboprop P-3 Orion antisubmarine aircraft. For this configuration, the mission profile and associated environmental conditions are given in Figures 5-6 and 5-7 respectively. The second configuration consists of captive carry on the A-6 Intruder, A-7 Cosair, and S-3 Viking aircraft. Each of these are jet powered patrol/attack aircraft. The mission profile, Figure 5-8, is the same for these aircraft with slightly different environmental conditions based on the performance characteristic of the individual aircraft, Figures 5-9 to 5-11. At the time of issue of References 3 and 4, platforms using the F/A-18 and B-52 were not established. Therefore, data is not available for these platforms.

Table 5.5 Air Based Mission Profiles

P-3 Orion	
Figures 5-6 and 5-7	24 Month cycle period 22 Month storage and transportation 21 Days intense period (500 hours) 23 Captive Carry Flights 85% ASW/SSSC mission 2 missiles/aircraft 15% Ready Alert (Attack) Mission 4 missiles/aircraft
A-6 Intruder	
Figures 5-8 and 5-9	24 Month cycle period 23 Month storage and transportation 31 Day intense period 93 Captive Carry Flights
A-7 Cosair	
Figures 5-8 and 5-10	24 Month cycle period 24 Month Storage and Transportation One strike mission 2-4 missiles/aircraft
S-3 Viking	
Figures 5-8 and 5-11	24 Month cycle period 23 Month Storage and Transportation 31 Day Intense Period 62 Captive Carry Flights ASW/SSSC Mission (100% of time; Long Range) 2 missiles/aircraft

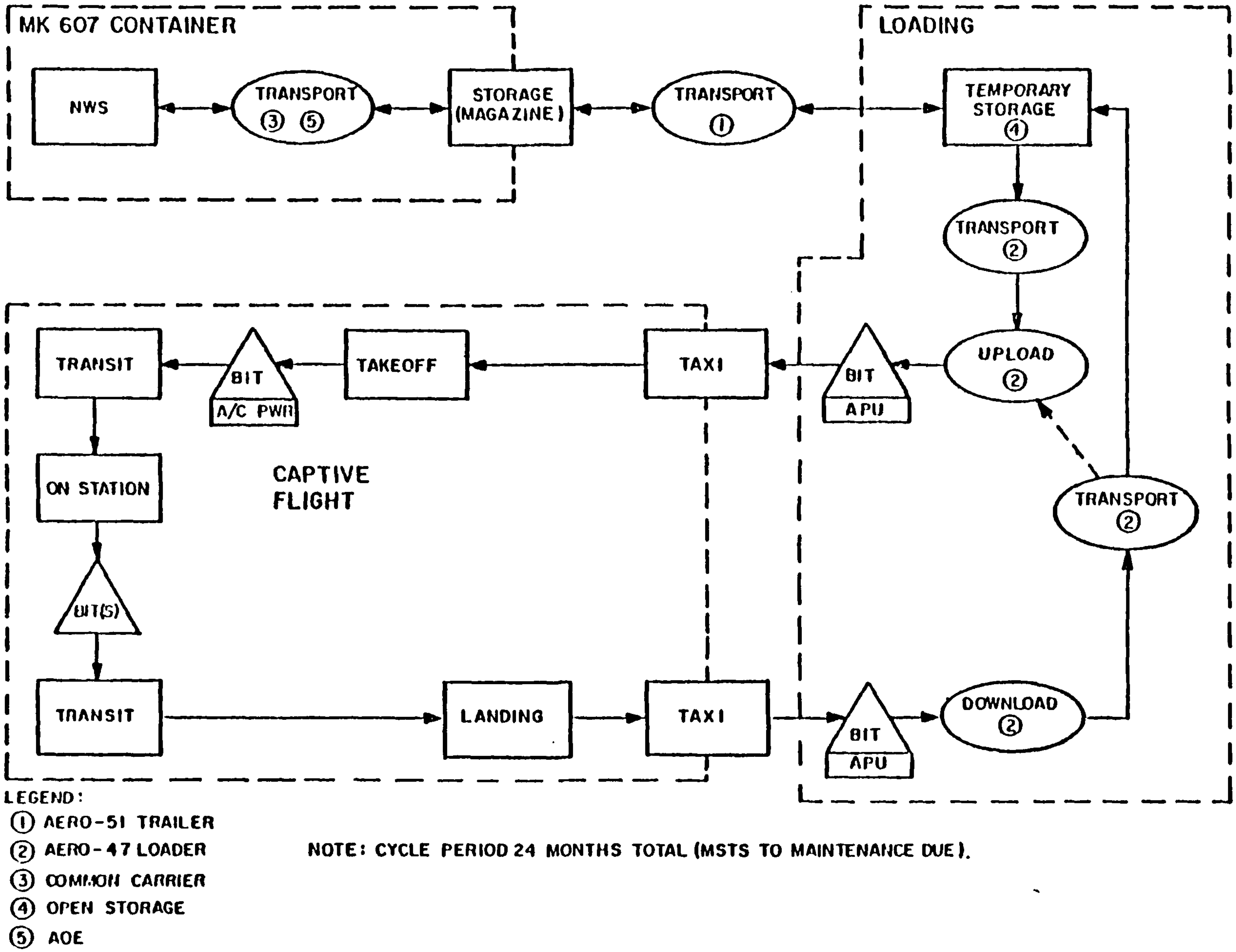


Figure 5-6 HARPOON Mission Profile, P-3 Aircraft Configuration (Typical) (References 3 and 4)

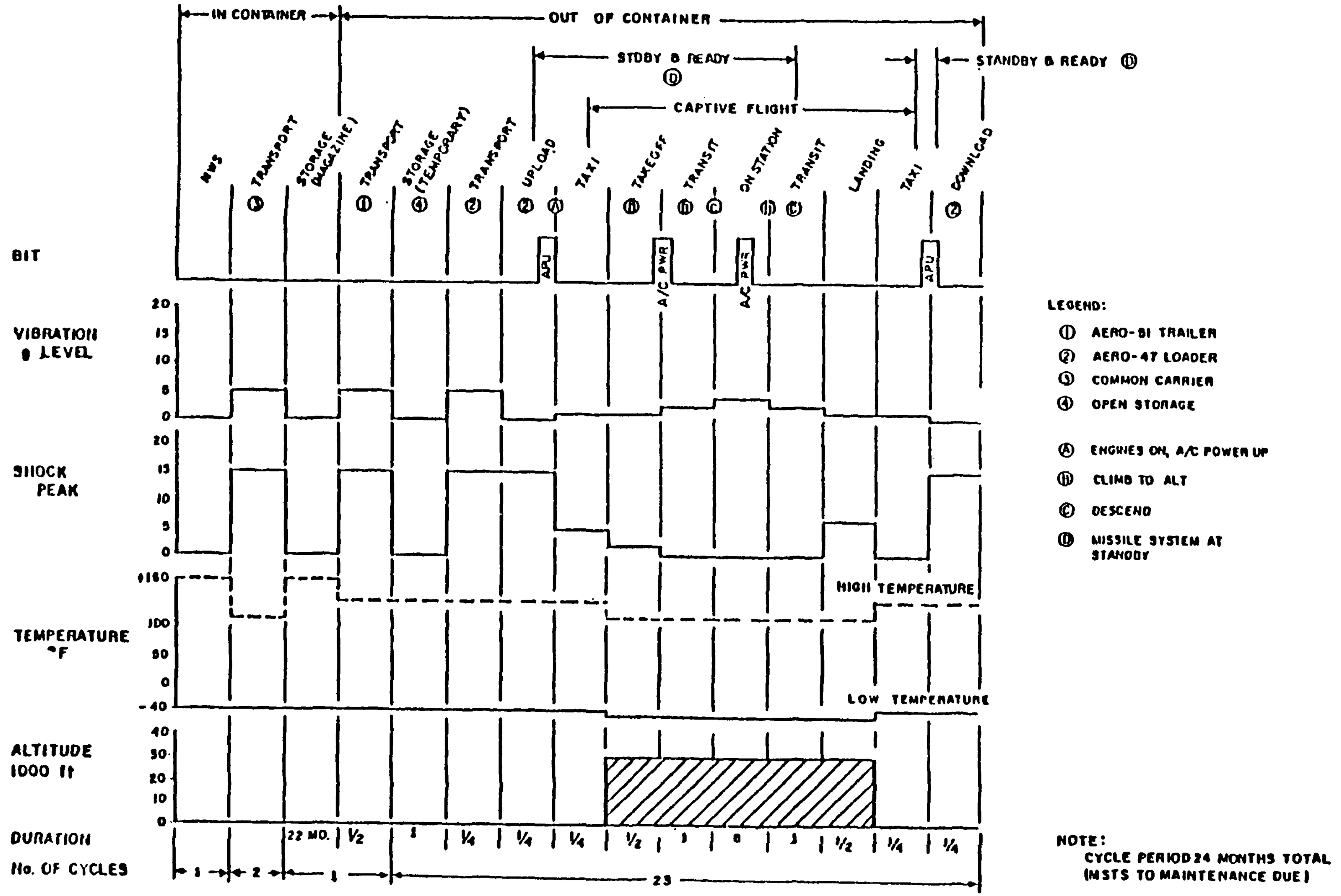


Figure 5-7 HARPOON Mission Profile, P-3 Aircraft Configuration (References 3 and 4)

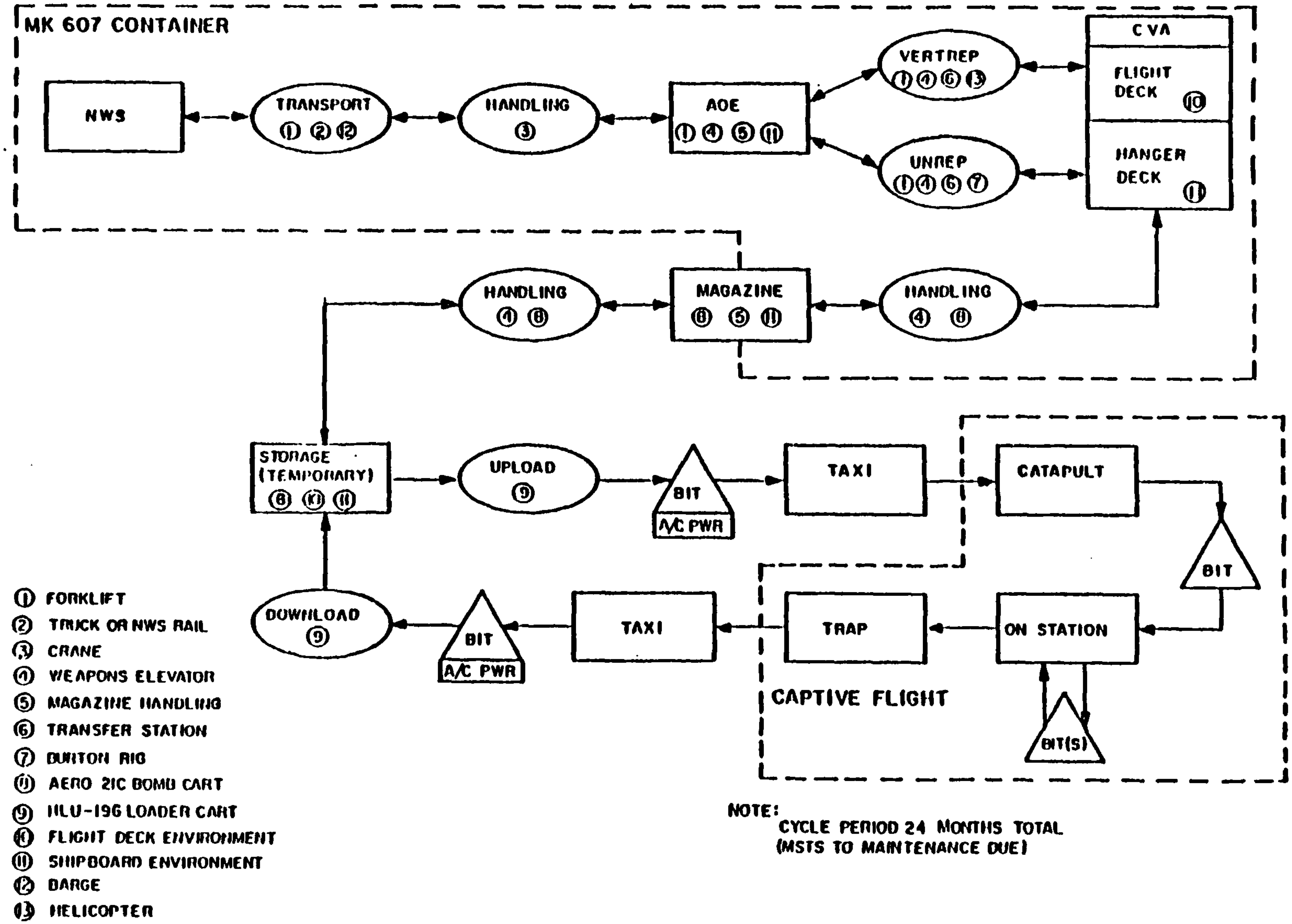


Figure 5-8 HARPOON Mission Profile, A-6/A-7/S-3/Air Configuration (Typical) (References 3 and 4)

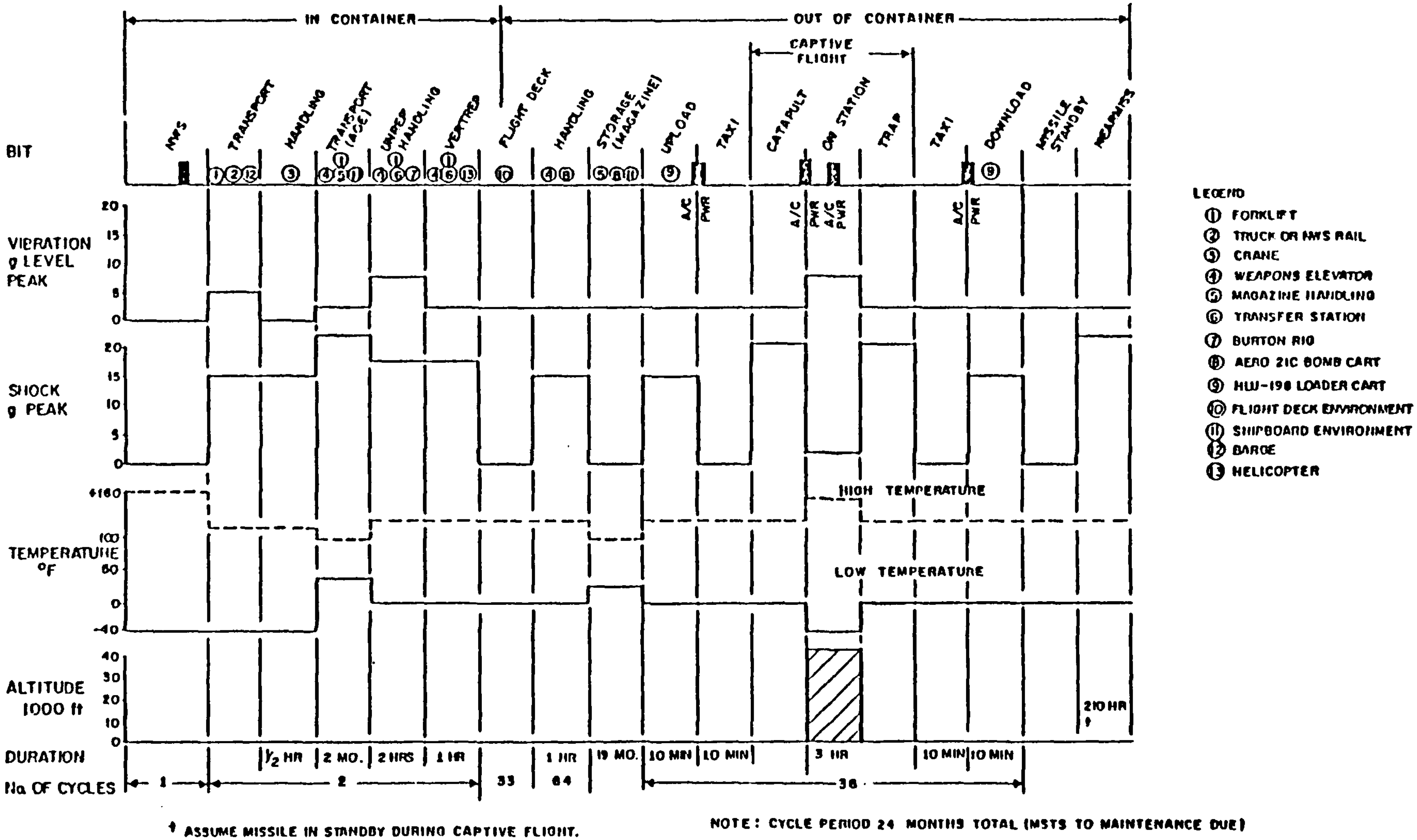


Figure 5-9 HARPOON Mission Profile, A-6/Air Configuration (References 3 and 4)

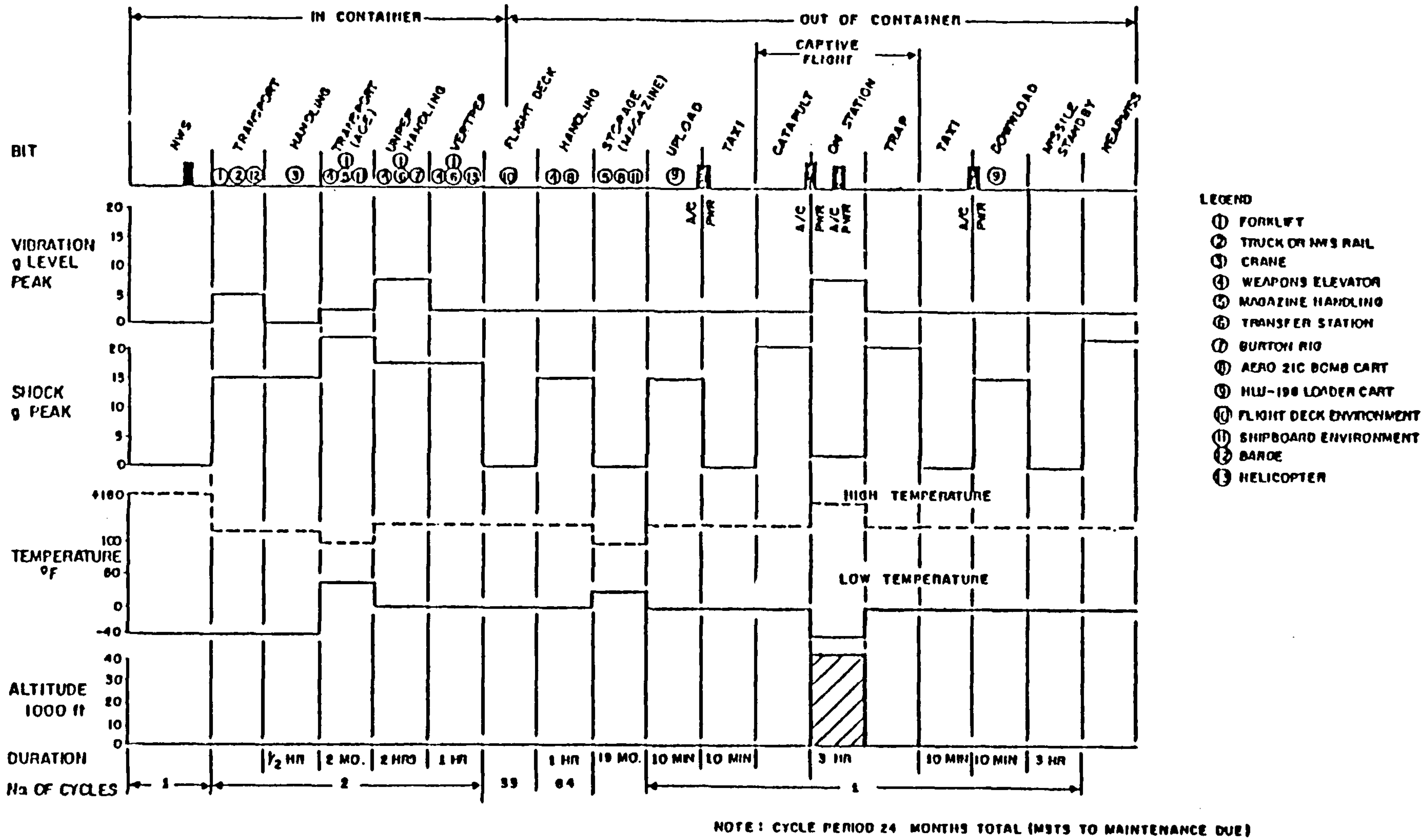
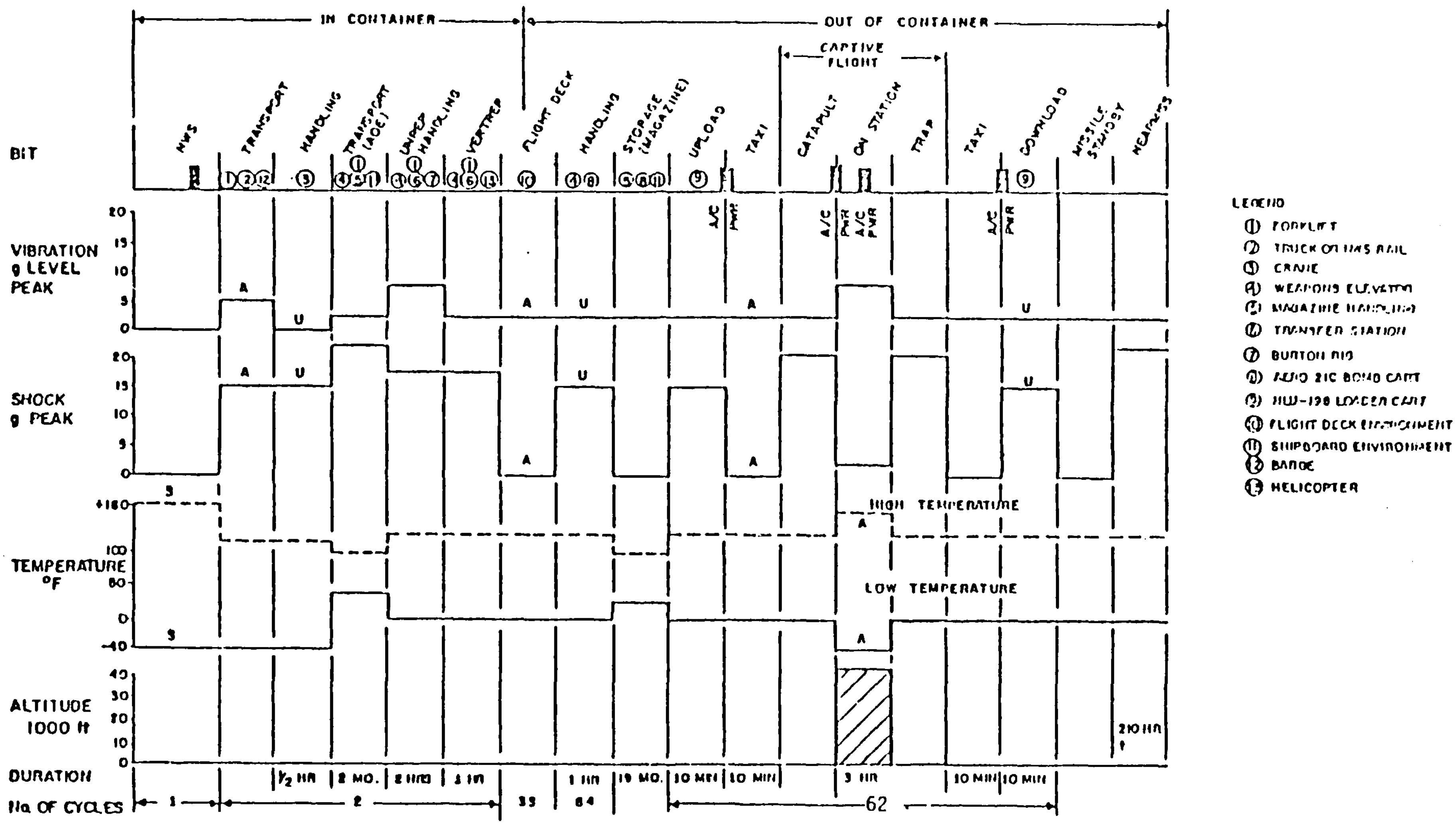


Figure 5-10 HARPOON Mission Profile, A-7/Air Configuration (References 3 and 4)



† ASSUME MISSILE IN STANDBY DURING CAPTIVE FLIGHT.

NOTE: CYCLE PERIOD 24 MONTHS TOTAL (MSTS TO MAINTENANCE DUE)

Figure 5-11 HARPOON Mission Profile, S-3/Air Configuration (References 3 and 4)

As mentioned earlier, three phases of the life cycle were considered; storage and transportation, captive carry and free flight. The storage and transportation phase of the life cycle covers the entire life from manufacture to final disposition. In most cases, storage and transportation is accomplished with the missile installed in a container specifically designed for it. The MK 607 Container is utilized for transportation of all of the air carried HARPOON missiles. Those missiles destined for service on a CVA (Attack Aircraft Carrier), with A-7, A-6 and S-3 aircraft, are subjected to additional transportation and storage loads on the AOE (Fast Combat Support Ship) and during onload and handling on the flight and hanger decks. All of these conditions are with the missile in the MK 607 Container. After removal from the container, the P-3 configuration is subjected to additional transportation, handling and storage levels similar to that seen with the missile in the container.

For a given configuration, the captive carry portion of the life cycle is that period during which the missile is on station ready for use. For this project we will define the captive carry portion of the mission profile for this air based platform to occur between take-off and landing of the aircraft. This does not include any taxi conditions which are enveloped by other environmental extremes. The P-3 captive carry conditions are defined as consisting of 23 flights, each lasting approximately 12 hours.

The three patrol/attach aircraft defined captive carry environments are identical in level. Each of the flights last approximately three hours. The A-6 mission profile consists of 93 flights, the A-7 has only one flight and the S-3 has 62 flights. Each of these flights has additional loads associated with temporary storage, upload/download and taxi. All of these will in one way effect the lifetime of the missile.

BITs are performed at various stages during the mission profiles. It is during these BIT tests that the functionality of the missile is determined. For the air configurations the defined times of the BITs are identical. A BIT is performed at the Naval Weapons Station (NWS) prior to shipment to the fleet. BITs are also performed after each upload, after takeoff and prior to each download. These are to insure that the missile is functional prior to the mission and to determine if any damage was done during the mission. BITs are also performed during the flight when the aircraft is on station to insure that the missile is in the ready state.

5.2.2.2 Ship Based Platforms

Each of the four ship based systems has a unique mission profile and associated environmental levels, Figures 5-12 to 5-19. In each case the total cycle time between return to the NWS is defined as 24 months. Of this time a total of 18 months is spent in the captive carry condition. With the exception of the PHM (Patrol Combatants Missile Hydrofoil) the 18 months is divided into three cycles of 6 months apiece.

Table 5.6 Ship Based Mission Profiles

ASROC	
Figures 5-12 and 5-13	24 Month cycle period 6 months on AOE (fast combat support ship) Cycle period 18 months total, 3 cycle, 6 month/cycle/FF (Frigate) Missiles in standby until selected
TARTAR	
Figures 5-14 and 5-15	24 Month cycle period 6 months on AOE Cycle period 18 months total, 3 cycle, 6 month/DDG or FFG (Guided missile destroyer or guided missile frigate) Missile loaded on launcher once for launch
CANISTER Lightweight (LW)	
Figures 5-16 and 5-17	On PHM for 18 months (Patrol Combatants Missile Hydrofoil) Alongside tender at 1 month intervals 6 months of operation 5 month peacetime 1 month intense period
CANISTER Grade-B	
Figures 5-18 and 5-19	24 Month cycle period 6 months on AOE Cycle period 18 months total, 3 cycle, 6 month/DDG, CG or DD (Guided missile cruiser or destroyer) Missile not in standby until selected
CANISTER Thickwalled	Not defined

The initial transportation, handling and transport by AOE (if required) for each configuration is the same. In all cases the missiles are in containers for these periods. The difference is the containers used to ship the missiles in. For the first two CANISTER configurations the missiles are shipped in the CANISTER in the MK 631 container. This could have a significant influence on the level of vibration and shock seen by the missile since the levels are constant as input into the container. The ASROC and TARTAR configuration are shipped in MK 608 and MK 632 containers respectively.

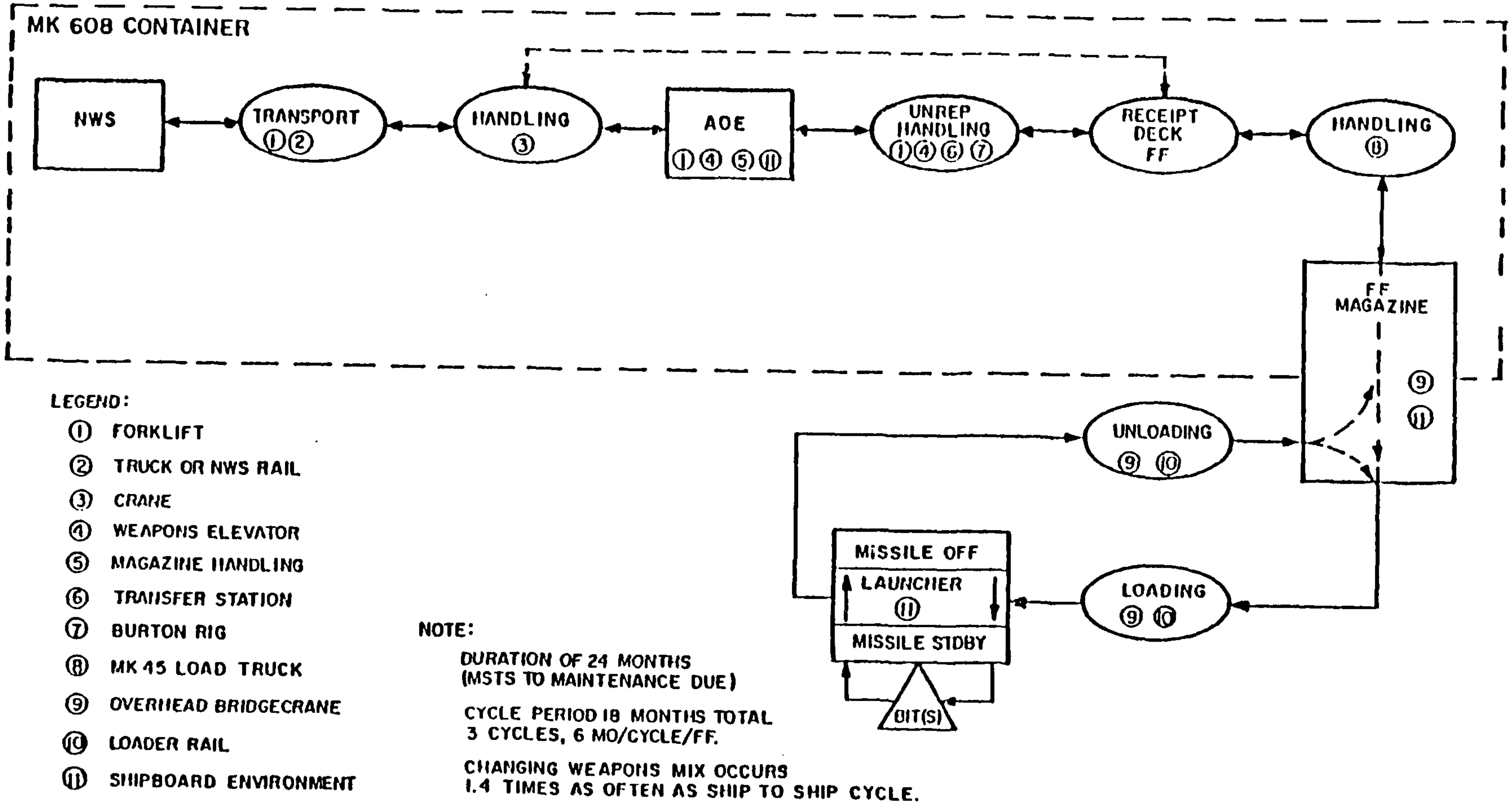
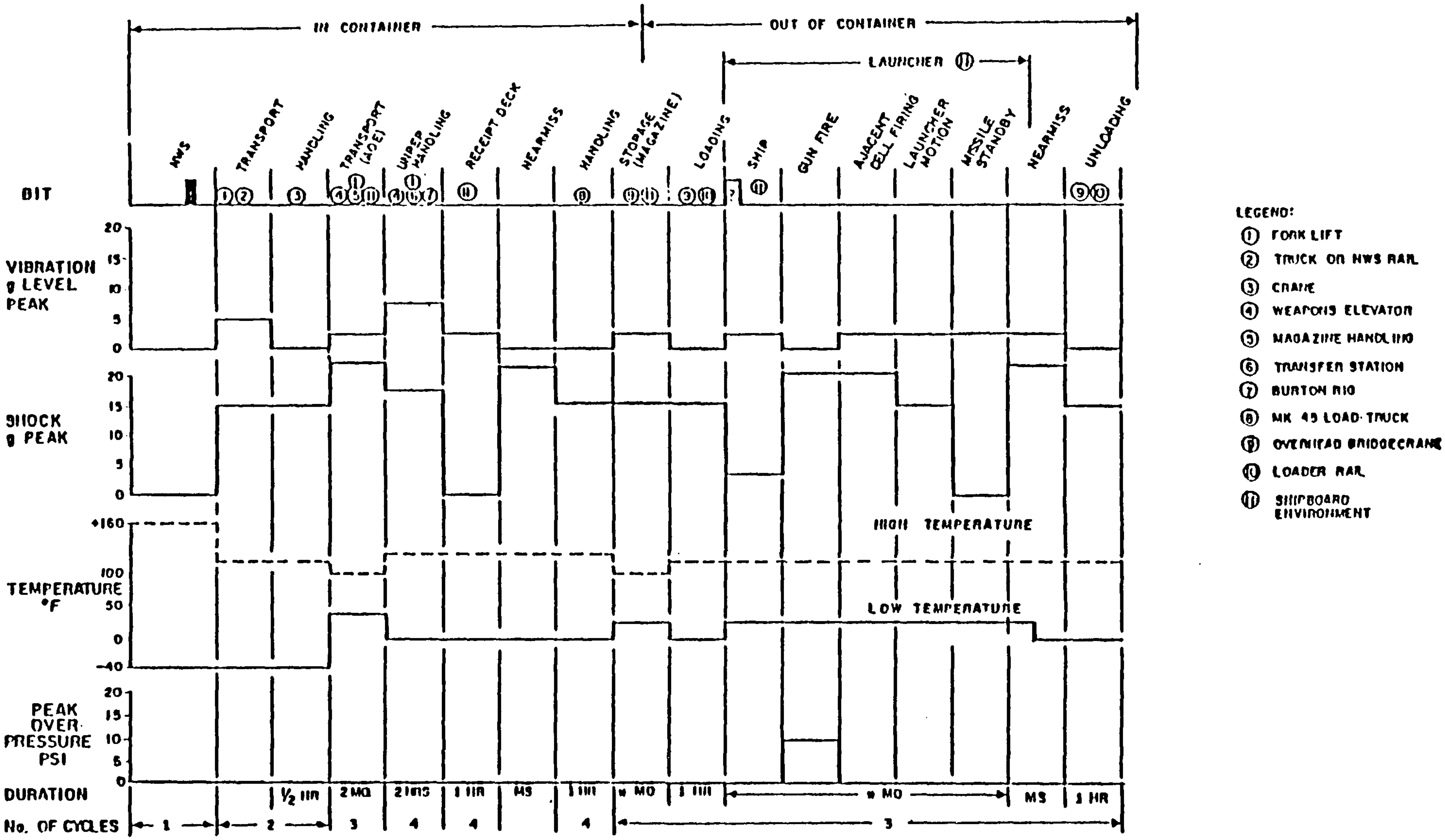


Figure 5-12 HARPOON Mission Profile, ASROC Configuration FF/ASROC (Typical) (References 3 and 4)



* TOTAL CUMULATIVE TIME 6 MONTHS.
MISSILE NOT IN STANDBY UNTIL SELECTED.
A/C HEATERS OPERATE AUTOMATICALLY.

NOTE: SALT SPRAY AND 100% REL. HUMIDITY ASSUMED.
DURATION OF 24 MONTHS (MSTS TO MAINTENANCE DUE)
CYCLE PERIOD 18 MONTHS TOTAL, 3 CYCLES, 6MO/CYCLE/TF.
CHANGE WEAPONS MIX OCCURS 1.4 TIMES AS OFTEN AS SHIP TO SHIP CYCLE.

Figure 5-13 HARPOON Mission Profile, ASROC Configuration (References 3 and 4)

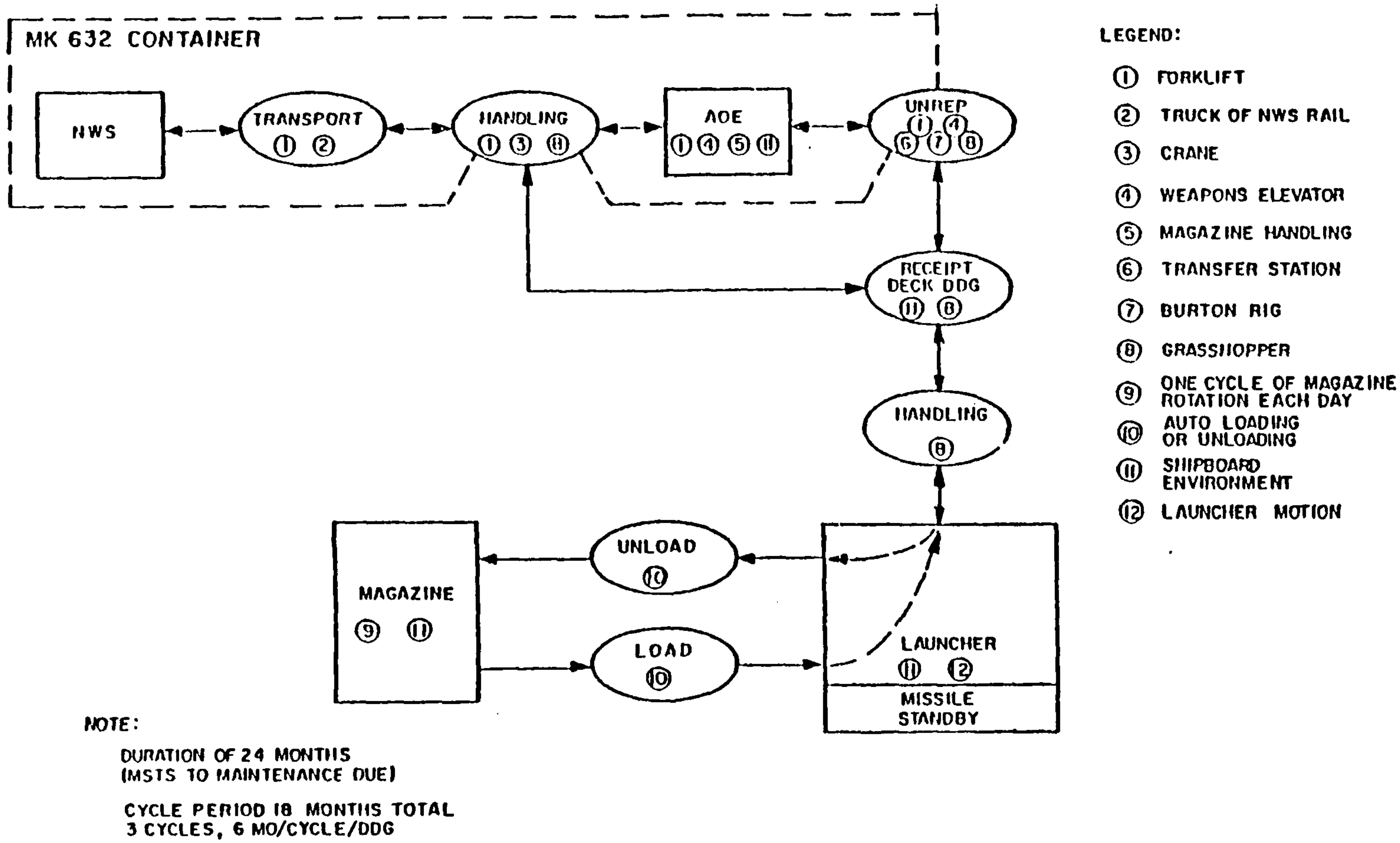


Figure 5-14 HARPOON Mission Profile, TARTAR Configuration DDG/FFG-7/TARTAR (Typical) (References 3 and 4)

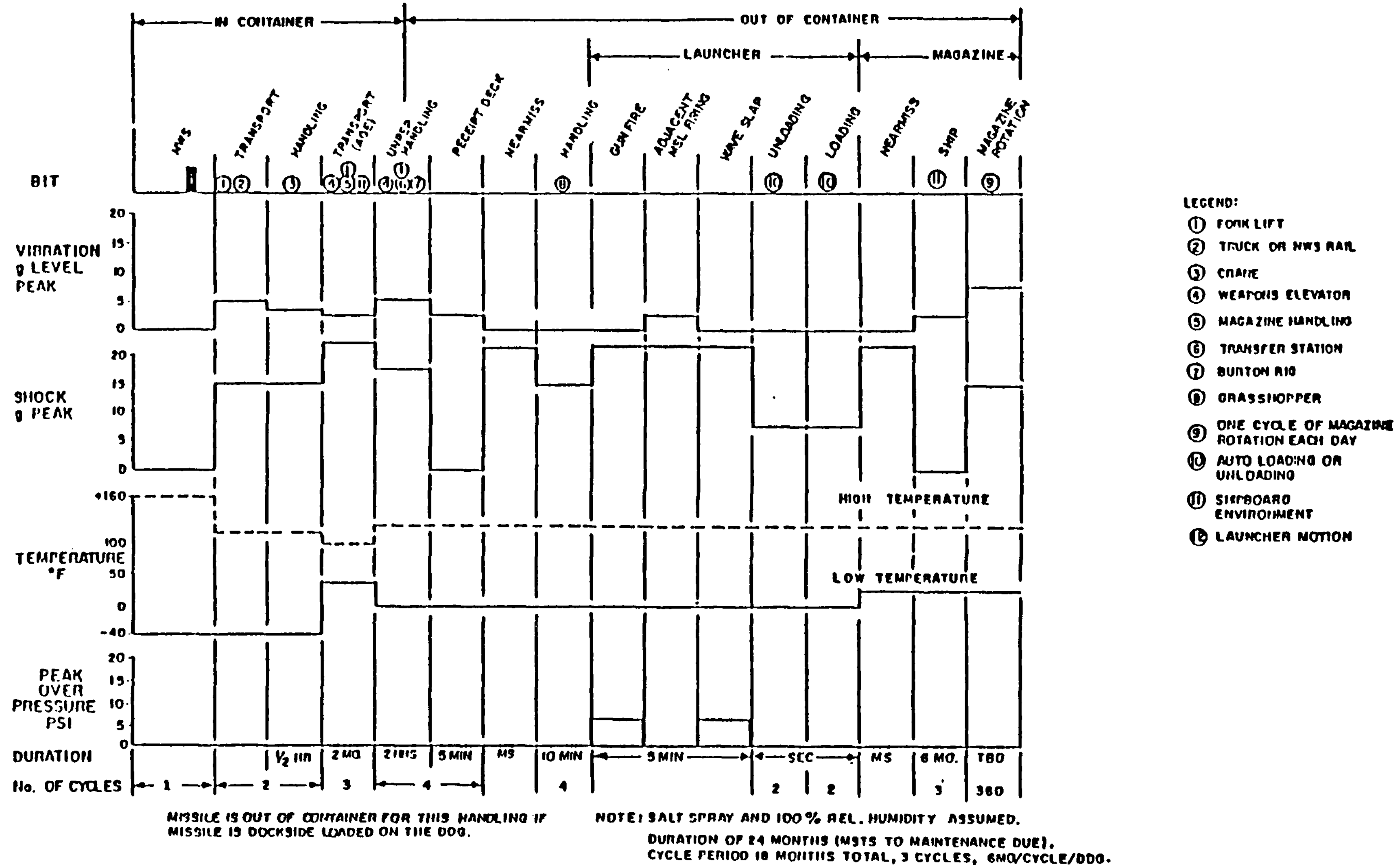
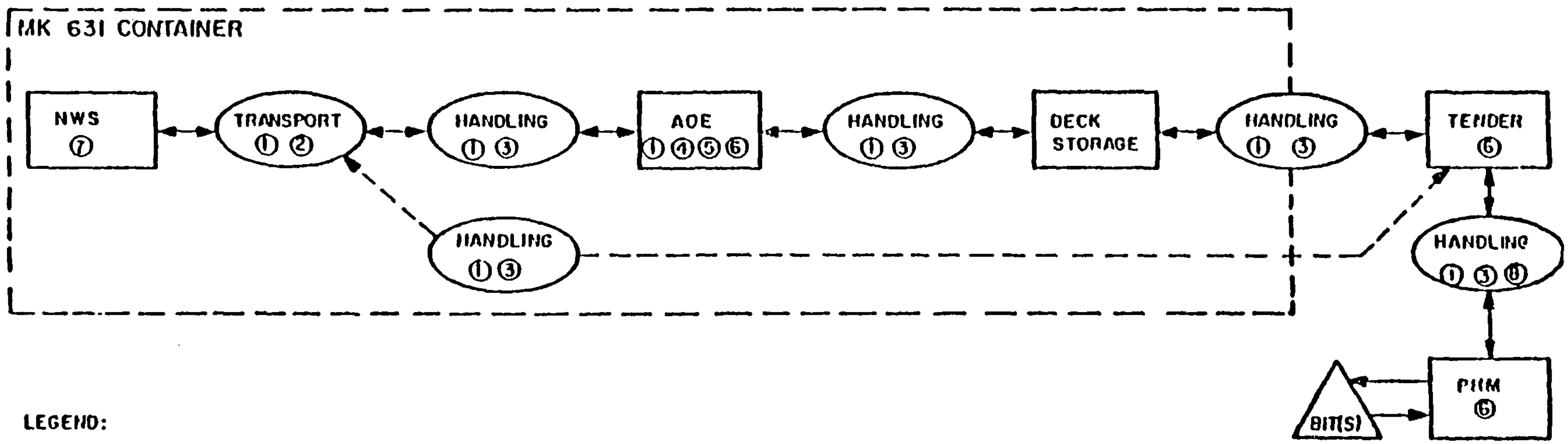


Figure 5-15 HARPOON Mission Profile, DDG/FFG/TARTAR Configuration (References 3 and 4)



LEGEND:

1. FORKLIFT
2. TRUCK OR NWS RAIL
3. CRANE
4. WEAPONS ELEVATOR
5. MAGAZINE HANDLING
6. SHIPBOARD ENVIRONMENT
7. CANISTERIZING
8. HARPOON HOIST ROTATION BEAM

NOTE: CYCLE PERIOD 24 MONTHS TOTAL (MSTS TO MAINTENANCE DUE)

Figure 5-16 HARPOON Mission Profile, PHM/Canister Configuration (References 3 and 4)

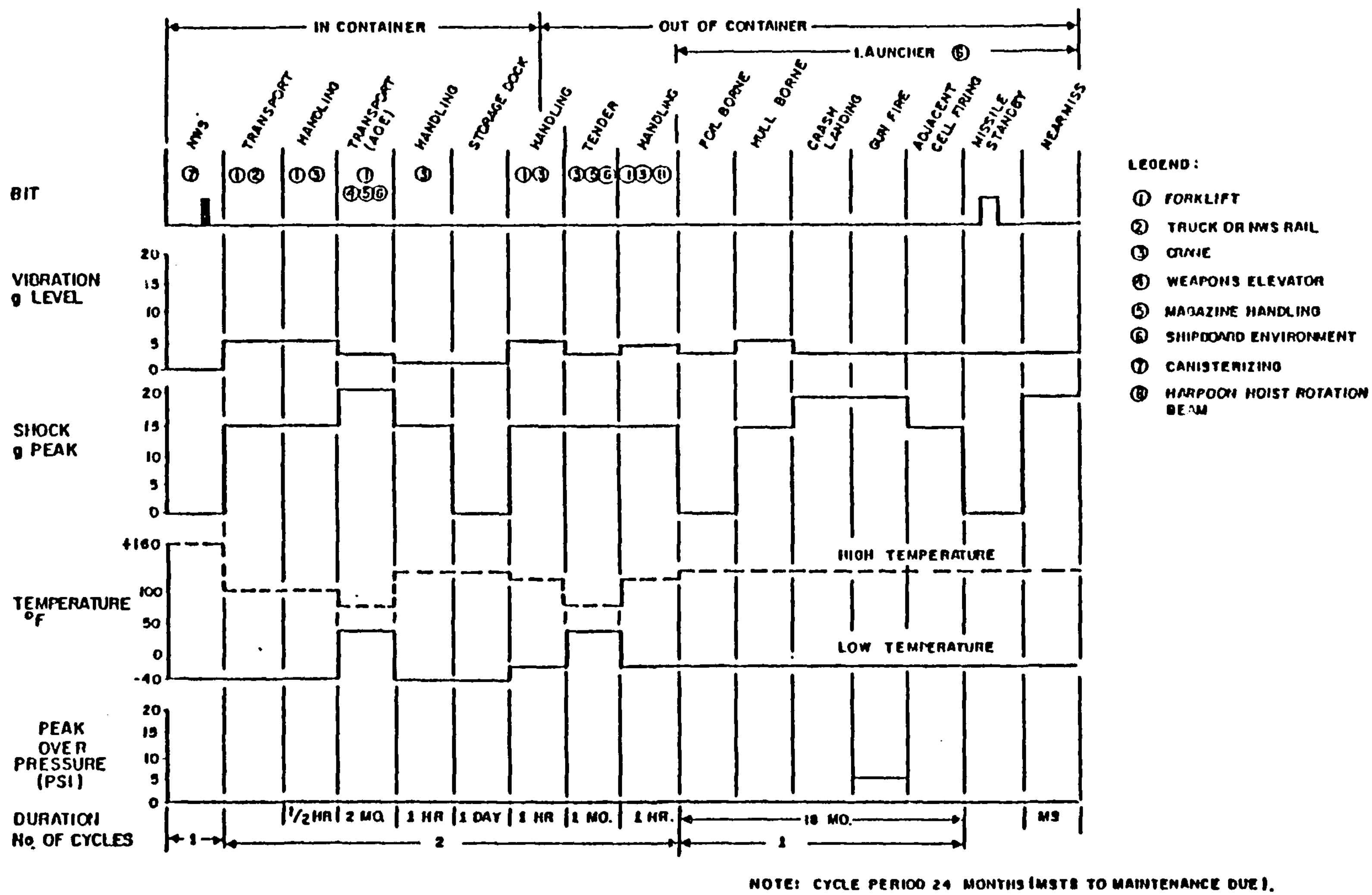
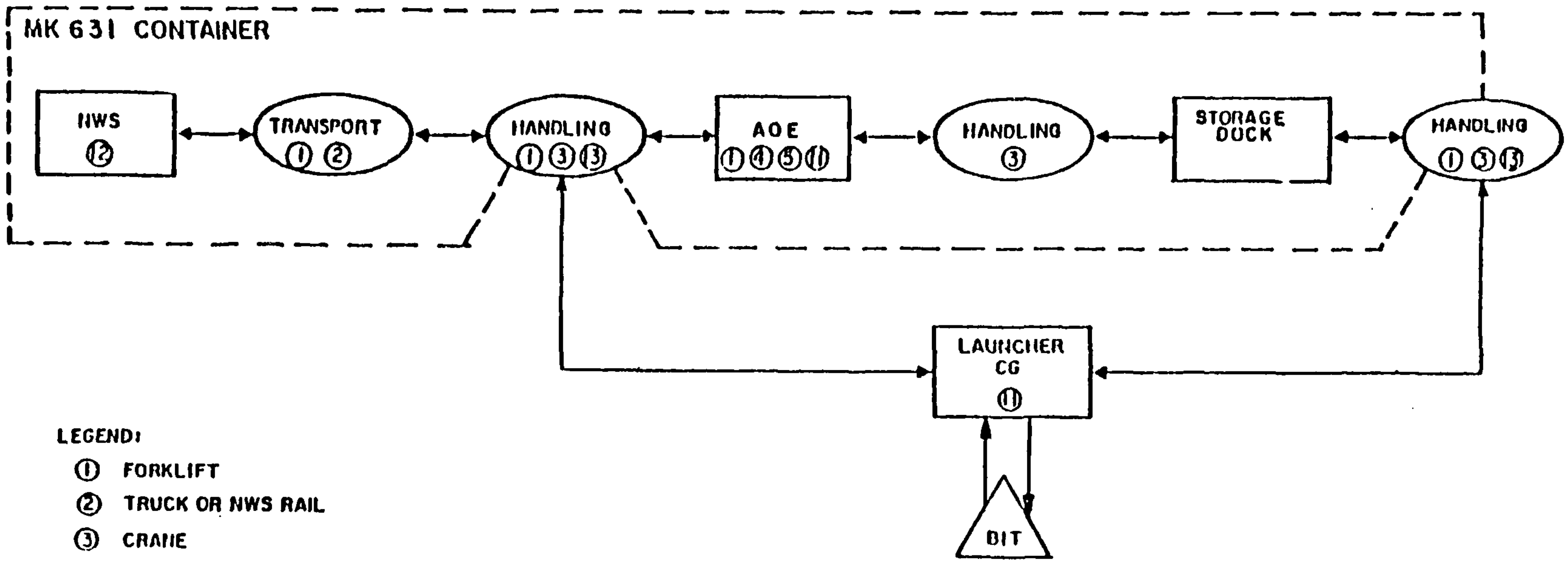


Figure 5-17 HARPOON Mission Profile, PHM/Canister Configuration (References 3 and 4)



LEGEND:

1. FORKLIFT
2. TRUCK OR NWS RAIL
3. CRANE
4. WEAPONS ELEVATOR
5. MAGAZINE HANDLING
6. TRANSFER STATION
7. BURTON RIG
8. MK 45 LOAD TRUCK
9. OVERHEAD BRIDGECRANE
10. LOADER RAIL
11. SHIPBOARD ENVIRONMENT
12. CANISTERIZING
13. HARPOON HOIST ROTATION BEAM

NOTE:
DURATION OF 24 MONTHS
(MSTS TO MAINTENANCE DUE)

CYCLE PERIOD 18 MONTHS TOTAL
3 CYCLES, 6 MO/CYCLE/CG

Figure 5-18 HARPOON Mission Profile, Canister Configuration DDG-37/CG-DD-963/Canister (Typical) (References 3 and 4)

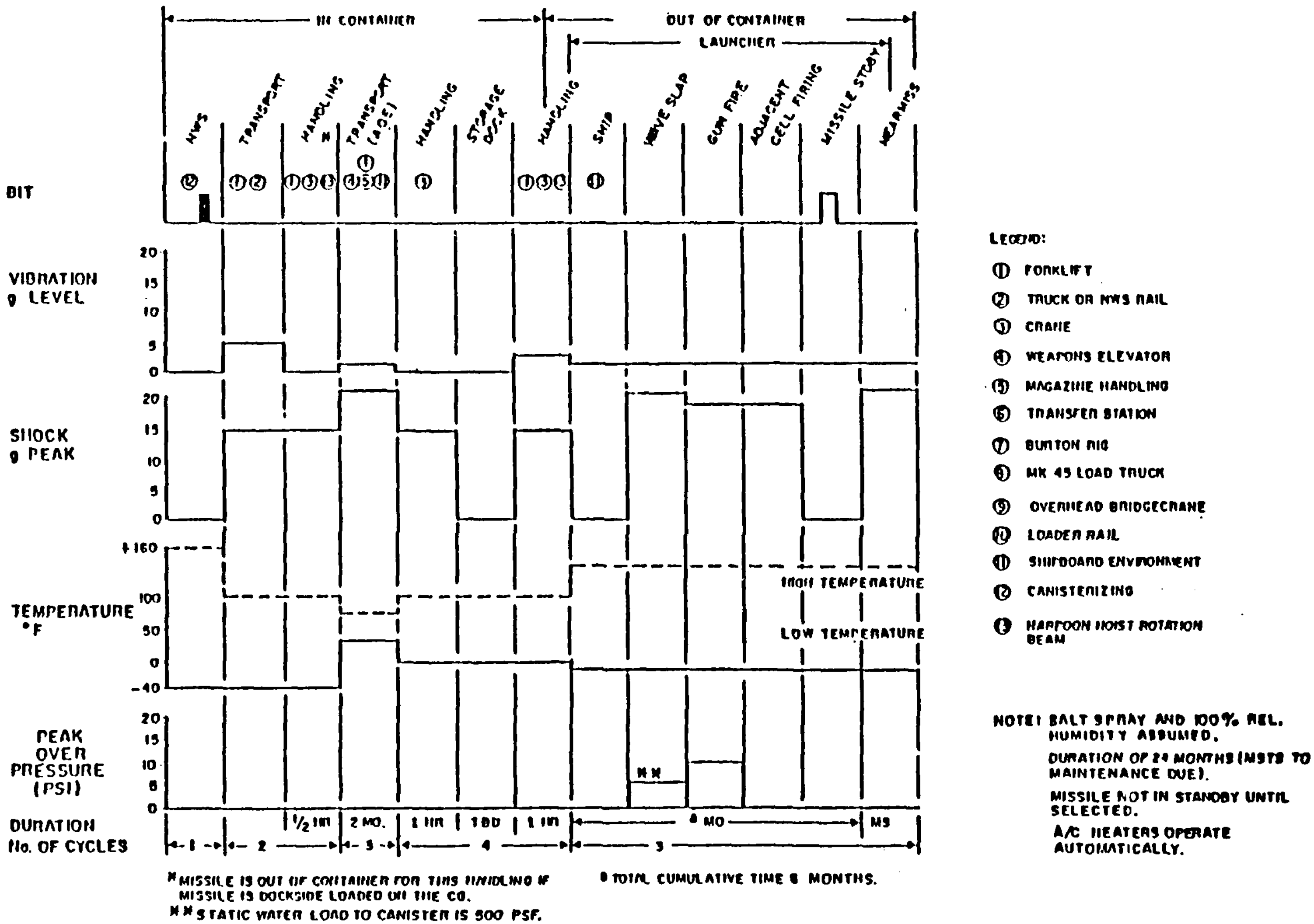


Figure 5-19 HARPOON Mission Profile, DDG-37/CG-DD-963/Canister (Typical) (References 3 and 4)

The ASROC configuration is onloaded to the frigate in its container. It can be stored onboard in this configuration for a period of time. Following unloading from the container the missile is stored in the ships magazine and later transferred to the launcher. For the ASROC configuration BIT tests are performed on the NWS and during the time that the missile is in the launcher.

The TARTAR configuration is removed from its container prior to onloading to the frigate or destroyer. While onboard the missile is either in the magazine or on the launcher. For the TARTAR configuration the only time a BIT is performed is at the NWS. There is no indication from the mission profile that it is performed at any other time during the cycle.

Up to the point where the missiles are installed on the launcher the CANISTER configurations have similar mission profiles with identical environmental levels. For the Grade B configuration the time on the launcher is divided up into three six month periods. The LW Canister is carried on a hydrofoil. BITS are performed for these configurations are performed at the NWS and periodically while the missile is on the launcher.

5.2.2.3 Submarine Based Platforms

The final configuration is the submarine based CAPSULE. In this configuration the missile is captive carried on a submarine and fired out of the torpedo tube. It then floats to the surface inside the capsule which once on the surface acts as a launcher for the system. The missile is assumed to be onboard a submarine for a total of 18 months during two nine month patrols. During this nine month period the submarine is assumed to be underway for a total of five months. The remainder of the time will be spent in port. As with the CANISTER configuration the CAPSULE configurations missile is transported inside the capsule inside a container, MK 630.

Table 5.7 Sub Based Mission Profiles

CAPSULE	
Figures 5-20 and 5-21	24 month cycle period 6 months total time on AOE/tender Cycle period 18 months total, 2 cycles, 9 months/cycle 9 month patrol cycle 3 month home port, 2 week transit, 2 month patrol, 1 month port, 2 month patrol, 2 week transit to home port Two tubes loaded with HARPOON and four HARPOONs per boat

For the submarine configuration the missile is subjected to BIT a variety of times during the mission profile. As with all other configuration a BIT is performed at NWS. In addition, BITs are preformed after tube loading, during the time the missile is in standby in the tube and just prior to tube unload. This level of BIT testing allows for a good definition of the true time of failure of the system.

5.2.2.4 Summary

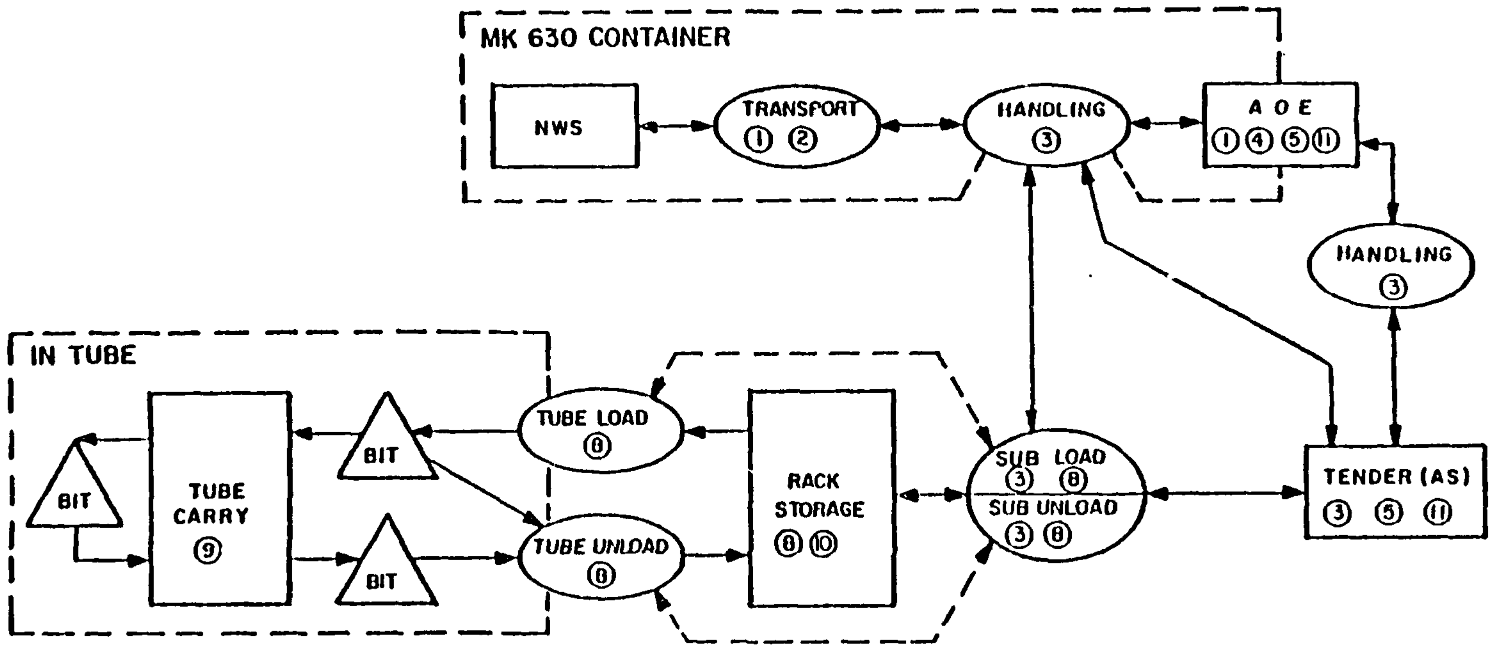
We have presented some details of the mission profiles for each of the three platforms, air, sea and submarine. This informations is necessary in the overall tailoring process to define the appropriate test conditions.

The profiles given only define five major types of environmental conditions: vibration, shock, temperature, altitude and peak over-pressure. The levels of the environments are defined, but their specific nature is not defined. In fact, References 3 and 4 state that "The levels of vibration, shock, temperature, altitude, over-pressure, etc. are only relative levels. They are only presented for comparison of magnitudes and do not represent specific values. The Environmental Deployment Profile will address the individual events in a more descriptive and specific manner."

The deployment profile, Figure 5-22, was included as an enclosure in References 3 and 4. To fully develop the environmental levels, other references and engineering judgement will be used to define the specific nature of the conditions.

The mission profiles presented, Figures 5-7 to 5-21, are those that were established at the beginning of the development program for the HARPOON. All information presented in this document will be based on this information although it is apparent that current service profiles do not match those given. It was not part of this task to look at current service use and update this information. This task will be necessary if more detailed upgrades in the test requirements are warranted.

As indicated earlier, the mission profile defines a complete cycle at the period from shipment from the Naval Weapons Station (NWS) until return to the NWS. A given missile and WRA may be subjected to a number of complete cycles from the time it is introduced into service until it is finally disposed of. It is also interesting to note that a given WRA may be utilized in any number of the three platforms during it lifetime. Typically a given WRA, when returned to the Naval Weapons Station (NWS), will be retained with the current missile if possible. In this case it will see the same complete cycle a number of times. It is also possible that a given WRA may be removed from a missile and installed on another missile destined for a different platform. Therefore all WRA's must be designed and tested to withstand environments introduced by all three platforms and must include the worst case. When considering the potential for damage to the WRA, it is necessary to consider the amplitude and duration of the exposure in the failure model. This makes determination of the appropriate test levels and durations even more difficult.

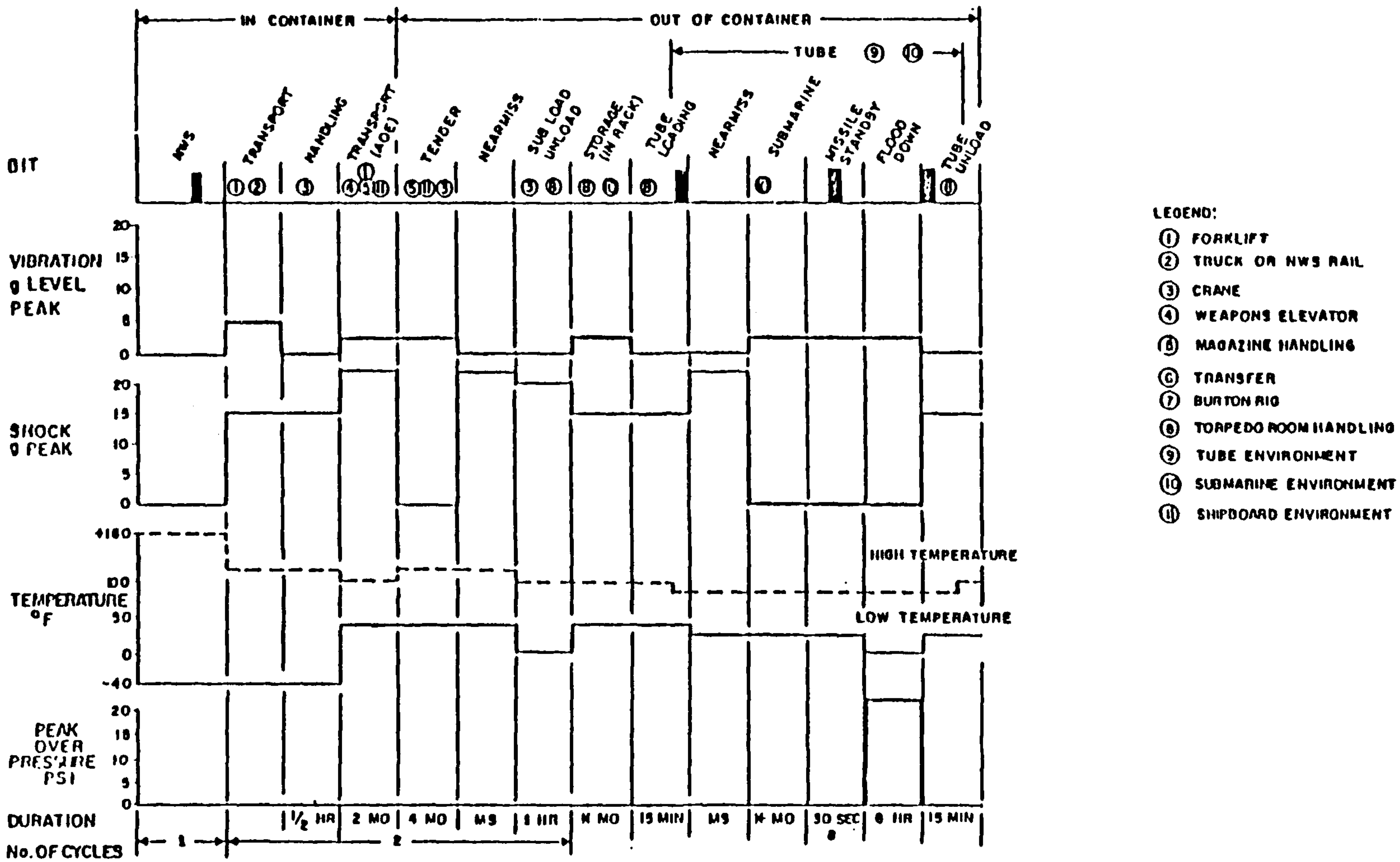


① FORKLIFT
② TRUCK OR NWS RAIL
③ CRANE
④ WEAPONS ELEVATOR
⑤ MAGAZINE HANDLING
⑥ TRANSFER STATION
⑦ BURTON RIG
⑧ TORPEDO ROOM HANDLING
⑨ TUBE ENVIRONMENT
⑩ SUBMARINE ENVIRONMENT
⑪ SURFACE SHIPBOARD ENVIRONMENT

NOTE:

CYCLE PERIOD 24 MONTHS
(MSTS TO MAINTENANCE DUE)
ONBOARD SUBMARINE – 18 MONTHS
ON PATROL – 9 MONTHS

Figure 5-20 HARPOON Mission Profile, SSN/Capsule Configuration (Typical) (References 3 and 4)



* TOTAL CUMULATIVE TIME 18 MONTHS

NOTE: SALT SPRAY AND 100% REL. HUMIDITY ASSUMED.
: CYCLE PERIOD 24 MONTHS TOTAL. (MSTS TO MAINTENANCE DUE)
: 9 MONTHS ON PATROL.

Figure 5-21 HARPOON Mission Profile, SSN/Capsule Configuration (References 3 and 4)

MISSILE	CANISTER	CAPSULE	CONTAINER IN	CONTAINER OUT	ELEMENT	EVENT	LEVEL	SOURCE/COMMENTS	SPECIFICATION REQUIREMENT
X	X	X	X		VIBRATION (TRANSPORTATION)	TRUCK ROUGH ROADS	2g RMS NARROW BAND RANDOM	REF: A SURVEY OF SHOCK AND VIBRATION ENVIRONMENTS IN THE FOUR MAJOR MODES OF TRANSPORTATION R.W. SCHOCK & W.E. PAULSEN	SAME DATA SOURCE
						TRUCK, PAVED ROADS	0.5g RMS NARROW BAND RANDOM		
						SHIP, EMERGENC MANEUVERS	3g pk PERIODIC		
						SHIP, ROUGH SEA	1g pk PERIODIC		
						RAIL TRANSIENT	5g RMS NARROW BAND RANDOM		
						RAIL, CONTINUOUS	3g RMS NARROW BAND RANDOM		
						AIR CARGO	5g RMS BROAD BAND RANDOM		
X	X	X	X		SHOCK (HANDLING)	FORKLIFT	22g pk	SANDIA LABS	NONE
X				X		AERO 51, TRAILER	15g pk		NONE
X				X	SHOCK (AIRCRAFT)	CATAPULT LAUNC	10g pk	ANALYSIS OF HARPOON MISSILE STRUCTURAL RESPONSE TO A/C LAUNCHES, LANDINGS, CAPTIVE FLIGHT & GUNFIRE. BOLT BARANEK & NEWMAN: PIERSOL	SAME DATA SOURCE
						ARRESTED LANDING	10g pk		
					VIBRATION (AIRCRAFT)	CAPTIVE CARRY P-3C, A-7C	5.8g RMS BROAD BAND RANDOM		

Figure 5-22 Environmental Deployment Profile (References 3 and 4)

MISSILE	CANISTER	CAPSULE	CONTAINER IN	CONTAINER OUT	ELEMENT	EVENT	LEVEL	SOURCE/COMMENT	SPECIFICATION REQUIREMENT
X	X			X	OVER PRESSURE	5 in. GUNFIRE	7psi (.48 ATM.)	LIMITS ESTABLISHED BY GUN CUT-OUT CAMS	7psi
X	X			X		WAVE SLAP	3.5psi (.24 ATM.)	NSWSES/STATIC H_2O HEAD	NONE
		X		X		TORPEDO TUBE FLOOD DOWN	CLASSIFIED	NUSC/FLOODED AT MAX. DEPTH APPLIED TO EXTERIOR OF CAPSULE	200 psi INADEQUATE
X				X	ALTITUDE	A-6 CAPTIVE CARRY	42K FT. (12.8 KM)		XAS-2400
X	X	X	X		TEMPERATURE	DUMP STORAGE	160° F (71°C)	MIL-STD-210B/DIURNAL CYCLE PEAK TEMPERATURE CONTAINER TEMPERATURE	160°F
X	X	X	X			DUMP STORAGE	-40°F (-40°C)	MIL-STD-210B	-40°F
		X		X		FLOODED TUBE	28°F (-2°C)	NUSC	28°F
						SUB CARRY	110°F (43°C)		110°F
X				X		HIGH ALTITUDE CAPTIVE CARRY	-60°F (-51°C)	MIL-STD-210B, NACA	-60°F
		X		X	SHOCK (NEARMISS)	NUCLEAR DEPTH CHARGE	CLASSIFIED	NUSC	NONE
						HIGH EXPLOSIVE DEPTH CHARGE	CLASSIFIED		XAS-2398 INADEQUATE
X				X	SHOCK	5 in. GUNFIRE	56g pk	NDAC-E, NWC/CALCULATED MECHANICAL SHOCK RESULTANT z	NONE

Figure 5-22 - (Continued) - Environmental Deployment Profile (References 3 and 4)

5.2.3 Environmental Design Criteria

One objective of this program is to develop sufficient information to compare field environments with current environmental test plan levels. The outcome will determine whether development of any new test plan is necessary.

To this point we have not defined the level and nature of the environmental conditions for the HARPOON. The mission profiles discussed in the previous section will be used to define the number and duration of various phases of the life cycle of the system. The levels of vibration, shock, temperature, altitude, overpressure, etc. presented in References 3 and 4 are only relative, designed for comparison of magnitudes. When considering the natural environment and platform factors the following need to be taken into account:

a) Magnitude of the natural environment.
b) Magnitude of platform induced environments.
c) Probability of occurrence of the environmental conditions.
d) Absolute and relative duration of exposure phase.
e) Number of times a phase will occur.
f) Expected effects and failure modes.
g) Effect on hardware performance and mission success.
h) Likelihood of problem's disclosure by test methods.
i) Experience gained from other equipment similarly deployed.

The magnitude of the natural environment will be discussed in this section. Data will be based on the information given in XAS-2381A [2] and supplemented by general information included in such documents as Mil-Std-810D [13] and Mil-Std-210C [18]. Levels defined in these documents are based in part on the probability of occurrence. Platform induced environments will be discussed briefly in this section and covered in more detail in section 5.3. The duration and number of cycles has been defined in the previous section.

The expected failure modes is an important aspect of this program since it is known that failures have occurred from review of field data, i.e. experience. A number of assumptions have been made on the most probable failure modes but they have not been fully verified with currently available analysis of the field data. One failure mode that has been defined is that associated with a moisture intrusion problem in one of the capacitors in the seeker. This would indicate that it will be important to look closely at procedures for humidity testing.

Consideration of the natural and induced environments on the various platforms has led to the conclusion that shock and vibration may be a driving factor in the reliability associated with the Canister based system. It is hypothesized that the level and duration of the exposure to these environments has a definite influence on the hardware capability to satisfy mission requirements. This failure mode has not been verified with analysis of the field data or the testing performed to date.

It is necessary to consider the environmental levels of the test program and the types of failure modes that they are designed to detect. In most instances qualification programs are established to define susceptibility to the various environments. The intent is to induce failures in a short period of test time that are representative of service data. They are not set up to determine mean times to failure, which is left to reliability testing.

Historically the levels of testing defined in Mil-Std-810 have proven to demonstrate the susceptibility of a specific piece of equipment to the service environment. Earlier versions of this document have defined specific test levels and durations for each of the environments. The driving force behind the adoption of Revision D of the standard was to tailor the testing to the particular field environments.

All the environments defined in XAS-2381A, Table 5.8, are at the external surface of the missile, canister, capsule or container, as applicable. Data is defined for the following program phases:

Table 5.8 Environmental Conditions as Defined in XAS-2381A

Program Phase	XAS-2381A Table
Transportation	I
Storage, Handling, and At-Sea-Transfer	II
Airfield and Carrier Storage and Handling	III
Captive and Free Flight	IV
ASROC Ship Storage, Handling, Launcher and Free Flight	V
Tartar-Terrier Ship Storage, Launcher and Free Flight	VI
Hydrofoil Ship Handling, Launcher, and Free Flight	VII
Submarine Handling, Launcher, and Free Flight	VIII
Drop Criteria	IX
Atmospheric Temperature	X

For this program, we only consider the phases associated with captive carry and free flight. It is interesting to note that there is no definition of the captive carry conditions for the CANISTER version of the missile, the one with the lowest reliability. The environmental conditions considered include: high and low temperature, humidity, rain, ice and hail, snow, sand and dust, shock, vibration, acceleration, gun blast loading, electromagnetic radiation, acoustics, high pressure and altitude. Not all conditions are applicable to all the program phases.

Mil-Std-810D defines test methods and procedures for all aspects of the service life of equipment; shipping/transportation, storage/logistic supply and mission/sortie use. In this document only those associated with the mission/sortie use for the HARPOON weapons system will be considered. Table 1.4 is a list of the applicable test methods defined in Mil-Std-810D, including specific procedures for the different platforms.

The environmental conditions given in XAS-2381A are summarized in Table 5.9. These are supplemented by a series of figures, some of which have been included in this report, Figures 5-23 to 5-34. The samples included are considered to be the conditions most likely to cause failure in the missile.

The variation of high temperature with time of day, Figure 5-23, is typical of published data, with maximum temperatures of 140° F. Recent work on temperature measurements on the HARPOON on hydrofoils have indicated temperatures up to 182° F [19]. Mil-Std-810D indicates induced temperatures from 145° F to 185° F for various climatic categories from basic hot to extreme induced. Similar data is contained in Mil-Std-201C.

Vibration data is given in Figures 5-24 to 5-28 for the three platforms considered; air, ship and submarine, as well as free flight. The captive flight environment at the missile forward lug, Figure 5-24 has an overall of 5.8 g_{rms}. This compares to a minimum integrity test for external store equipment in aircraft of 7.70 g_{rms} given in Figure 514.3-36 of Mil-Std-810D. The Mil-Std-810D is intended for small items, less than 75 lbs, and larger items, such as HARPOON will experience a lower level. The levels are significantly above those measured on the HARPOON [20]. This is typical where service levels are increased to test levels to reduce test time.

The free flight vibration levels for the sustainer and boost phases are given in Figures 5-25 and 5-26 respectively. The boost phase is applicable to the ship and submarine based systems. The levels generally increase as the location proceeds from the nose of the missile to the tail. Levels in the region of the seeker are given as 5.8 and 9.14 g_{rms} for the sustainer and booster phases respectively. Again these are higher than the levels given in Reference 20. The defined test curves envelope the series of narrowband peaks evident in the service data. Enveloping of such data can lead to a conservative test if the overall level is the primary cause of the failure mode rather than peaks at specific frequencies.

TABLE 5.9 XAS-2381A REQUIREMENTS

TEST	AIRFIELD HANDLING	AIRCRAFT CARRIER STORAGE	AIRCRAFT CARRIER HANDLING	CAPTIVE FLIGHT ENVIRONMENT VA (ATTACK)	CAPTIVE FLIGHT ENVIRONMENT VP & VS (PATROL)	FREE FLIGHT AIRCRAFT
Altitude	NA	NA	NA	Refer to XAS-2400	Refer to XAS-2400	Refer to XAS-2400
Temp (High)	140°F (2 hours)	Figure 3	110°F (2 hours)	105°F (1 hour), 155° F (10 min), 170° F (2 min), 105° F (1 hour), Return Consecutive Events	95° F (2 hour), 125° F (10 min), 155° F (2 min), 95° F (2 hour), Return Consecutive Events	170° F (1 min), 155°F (9 min)
Temp (Low)	-40°F (72 hours)	40° F (24 hours)	18° F (24 hours)	-50° F (4 hours)	-60° F (6 hours)	
Temperature Cycling	NA	NA	NA	NA	NA	-60° F to 45° F in 1 min, 45° F (1 min), 80° F (8 min)
Relative Humidity	Figure 14	Figure 14	Figure 14	Table X	Table X	Table X
High Pressure	NA	NA	NA	NA	NA	NA
Low Pressure	NA	NA	NA	NA	NA	NA
Pressure Change	NA	NA	NA	NA	NA	NA
Acceleration	NA	NA	NA	Calc from MIL-A-8591	Calc from MIL-A-8591	<u>Manuever</u> Long ± 1 g, Vert ± 5.2 g, Lat ± 2.1 g, acting simultaneously or 4 g in any radial direction. <u>Rack Ejection Levels</u> Figure 17
Vibration	Negligible		Negligible			
Random		NA				
Non-operational				Figure 12A	Figure 12A	NA
Operational						Figure 12B
Sinusoidal				NA	NA	NA
Non-operational		Figure 10				
Operational						
Acoustic	Negligible	NA	Negligible	Figure 13A	Figure 13A	Figure 13A
Shock						
Non-operational	15 g for 11-18 msec Halfsine wave, 3 axis	Figure 20	15 g for 11-18 msec Halfsine wave, 3 axis	Calc from MIL-A-8591	Calc from MIL-A-8591	NA
Operational	NA	NA	NA			Figure 16A and 16B
Pyro	NA	NA	NA	NA	NA	
Gun Blast	NA	NA	NA			

TABLE 5.9 XAS-2381A REQUIREMENTS (Cont'd)

TEST	ASROC STORAGE	ASROC HANDLING & LAUNCHER	ASROC FREE FLIGHT	TARTAR-TERRIER STORAGE	TARTAR ON LAUNCHER	TERRIER ON LAUNCHER	TARTAR-TERRIER FREE FLIGHT
Altitude	NA	NA	NA	NA	NA	NA	NA
Temp (High)	Figure 3	120°F (4 hours)	113°F to 155°F in 30 sec 155°F for 9.5 min	80°F (4 hours) 95°F (4 hours)	113°F (15 min)	113°F (15 min)	113°F to 155°F in 30 sec 155°F for 9.5 min
Temp (Low)	40°F (24 hours)	35°F (4 hours)		60°F with AC 40°F (4 hours)	-13°F (15 min)	-13°F (15 min)	
Temperature Cycling	NA	NA	-13°F to 80°F in 30 sec 80°F for 9.5 min	NA	NA	NA	-13°F to 80°F in 30 sec 80°F for 9.5 min
Relative Humidity	Figure 14	Figure 14	Table X	Figure 14	Figure 14	Figure 14	Table X
High Pressure	NA	NA	NA	NA	NA	NA	NA
Low Pressure	NA	NA	NA	NA	NA	NA	NA
Pressure Change	NA	NA	NA	NA	NA	NA	NA
Acceleration	Negligible	Long Vert Lat ±1.16 ± 1.08 ±0.48 ±0.75 ± 0.4 3 ± 1.48 ±1.70 ± 0.64 ±0.36	At Launch Long Vert Lat 15.0 ± 1.08 ± 0.48 15.0 ± 0.43 ± 1.48 <u>Maneuvering</u> Long Vert Lat ± 1.00 ± 2.10 ± 5.20 Acting Simultaneously or 4.0 g in any Radial Direction	NA	Combine Loads Of Long Vert Lat ± 0.5 ±3.5 ± 1.8 -1.8 ±0.4 ±3.5 -1.8 ±2.9 ± 1.1 Apply at missile cg	Combine Loads Of Long Vert Lat ± 1.9 ± 1.4 ± 3.3 -1.9 ±3.9 ±0.8 ± 0.08 ± 4.4 ± 1.8 Apply at missle cg	<u>At Launch</u> Long Vert Lat 15.0 ± 0.40 ± 3.50 15.0 ± 4.40 ± 1.80 <u>Maneuvering</u> Long Vert Lat ± 1.00 ± 5.20 ± 2.10 Acting Simultaneously or 4.0 g in any Radial Direction
Vibration Random Non-operational Operational Sinusoidal Non-operational Operational	 NA Figure 10 NA	 NA Figure 10 NA	 NA NA Figures 12B and 12C NA	 NA Figure 10 NA	 NA NA As defined in XAS-2381	 NA As defined in XAS-2381	 NA Figures 12B and 12C NA
Acoustic	Negligilbe	Figure 13A	Figures 13A and 13B	Negligible	Negligible	Negligible	Figures 13A and 13B
Shock Non-operational Operational Pyro Gun Blast	 Figure 20 NA NA Negligible	 Figure 20 NA Figure 15	 NA Figures 16A and 16B Negligible	 Figure 20 NA NA Negligible	 Figure 20 NA NA Figure 15	 Figure 20 NA Figure 15	 NA Figures 16A and 16B NA

TABLE 5.9 XAS-2381A REQUIREMENTS (Cont'd)

TEST	CANISTER STORAGE	CANISTER LAUNCH SUPPORT	CANISTER FREE FLIGHT	HYDROFOIL HANDLING	HYDROFOIL LAUNCHER	HYDROFOIL FREE FLIGHT
Altitude				NA	NA	NA
Temp (High)				Figure 19	Figure 19	113° F to 155° F in 30 sec 155° F for 9.5 min
Temp (Low)				-13° F (8 hours)	-13° F (24 hours)	
Temperature Cycling				NA	NA	-13° F to 80° F in 30 sec 80° F for 9.5 min
Relative Humidity				Figure 14	Figure 14	Table X
High Pressure				NA	NA	NA
Low Pressure				NA	NA	NA
Pressure Change				NA	NA	NA
Acceleration				Negligible	<u>Crash Landing</u> Long Vert Lat 1.41 ± 1.39 -3.63 1.77 ± 1.50 -3.42 2.44 ± 1.39 -3.04 <u>Foil Borne</u> Long Vert Lat 0.73 ± 0.29 -1.42 0.87 ± 0.29 -1.35	<u>At Launch</u> Long Vert Lat 15.0 ± 0.29 -1.42 <u>Maneuvering</u> Long Vert Lat ± 1.00 ± 2.10 ± 5.20 Acting Simultaneously or 4.0 g in any Radial Direction
Vibration Random Non-operational Operational Sinusoidal Non-operational Operational				Negligible	 NA Figure 10	 NA Figures 12A & 12B NA
Acoustic				Negligible	Figure 13B	Figures 13A and 13B
Shock Non-operational Operational Pyro Gun Blast				 15 g, 11-18 msec Halfsine wave, 3 axes NA NA NA	Negligible Negligible	 NA Figures 16A and 16B NA

TABLE 5.9 XAS-2381A REQUIREMENTS (Concluded)

TEST	SUBMARINE STORAGE AND HANDLING	SUBMARINE TO SURFACE	SUBMARINE FREE FLIGHT
Altitude	NA	NA	NA
Temp (High)	Figure 19 80° F in Air Condition 95° F (4 hours) on Rack 110° F (4 hours) in Tube	94° F	113° F to 155° F in 30 sec 155° F for 9.5 min
Temp (Low)	-20° F (8 hours), 60°F Air Condition 40° F (4 hours) on Rack 28° F (4 hours) in Tube	30° F	
Temperature Cycling	NA	NA	-13° F to 80° F in 30 sec 80° F for 9.5 min
Relative Humidity	Figure 14	Figure 14	Table X
High Pressure	15 psia	15 psia	15 psia
Low Pressure	15 pisa	15 pisa	13.5 psia
Pressure Change	NA	NA	Breech 15-75-15 psia in 60 msec
Acceleration	2.5 g's in 3 axes during hoisting	15 g axial 2 g in any Radial Direction	<u>Boost</u> Long Vert Lat 15.0 ± 2.00 ± 2.00 <u>Maneuvering</u> Long Vert Lat ± 1.00 ± 2.10 ± 5.20 Acting Simultaneously or 4.0 g in any Radial Direction
Vibration			
Random	NA	NA	
Non-operational			NA
Operational			Figures 12B and 12C
Sinusoidal			NA
Non-operational	Figure 10	NA	
Operational	NA	Figure 22	
Acoustic	Negligible	Negligible	Figures 13A and 13B
Shock			
Non-operational	Supplement C	NA	NA
Operational		Figures 16B and 21	Figures 16A and 16B
Pyro			
Gun Blast	NA	NA	

Does not include storage and handling except as associated with captive carry conditions.
Does not include rain, ice and hail, snow, sand and dust or electromagnetic radiation.
NA - Not applicable

Figures and Tables refer to those in XAS-2381A

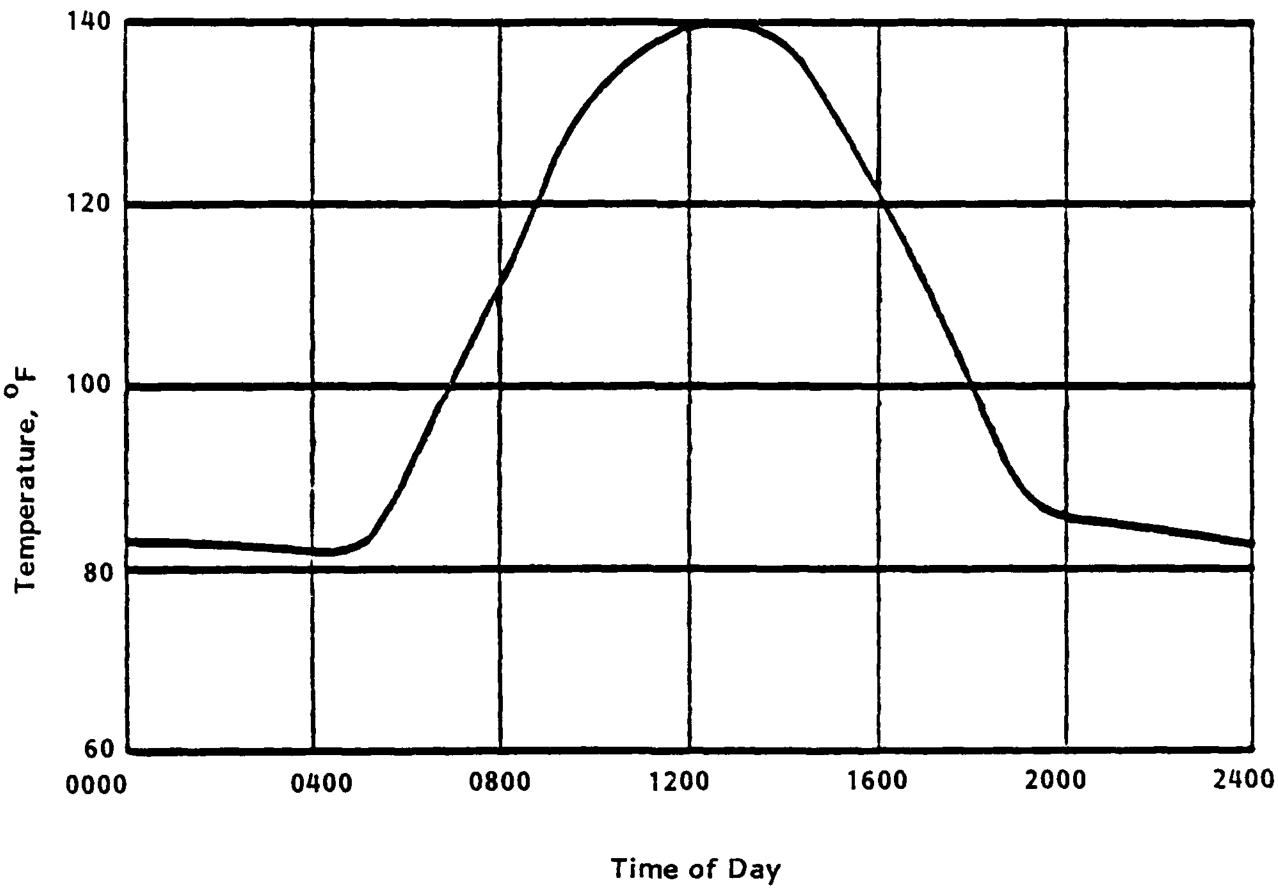


Figure 5-23 High Temperature Profile for Capsule and Canister Skins for Handling and Canister Skin While Installed in Hydrofoil Ship (Reference 2)

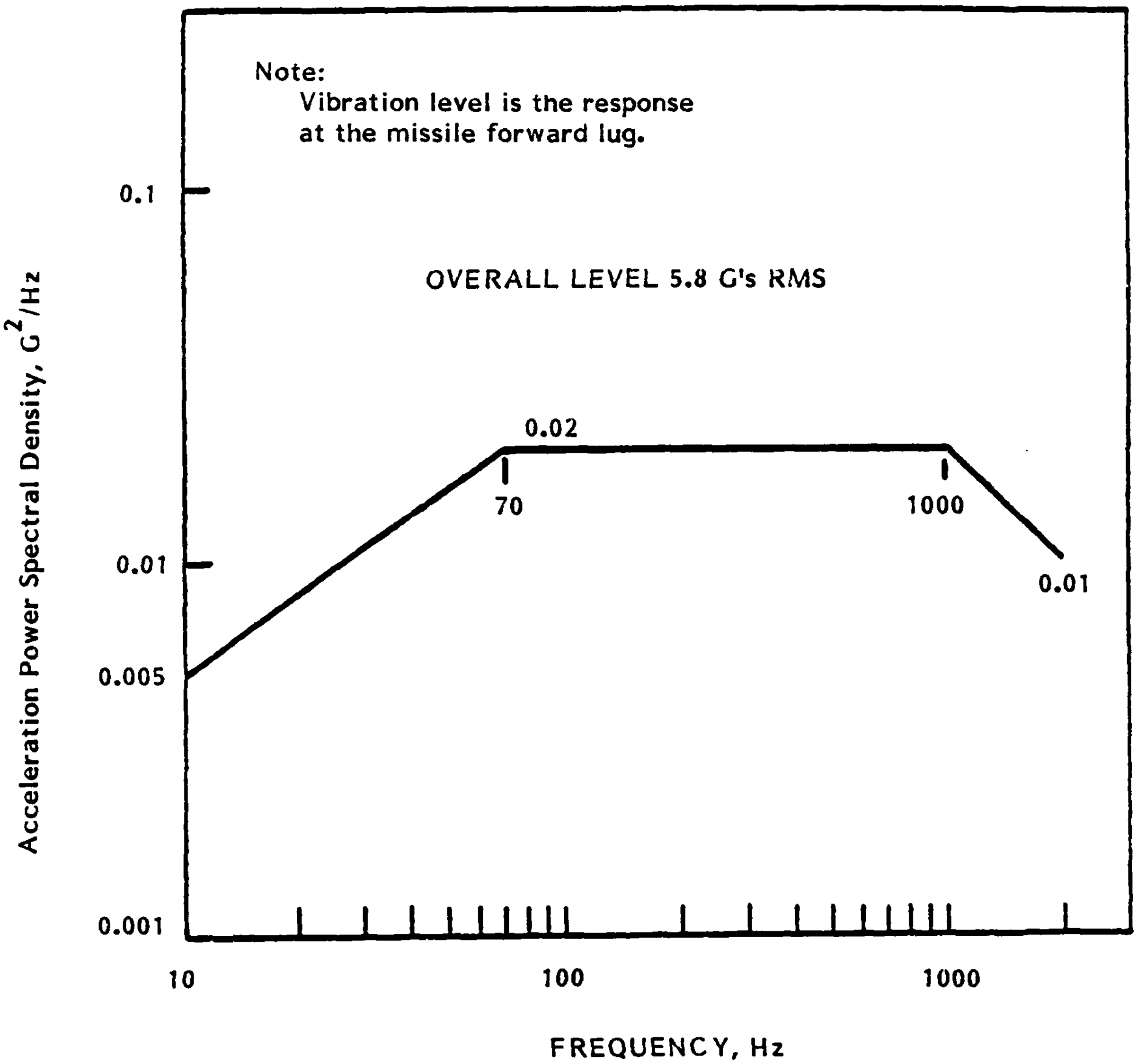


Figure 5-24 HARPOON Missile Vibration Environment, Captive Flight (Reference 2)

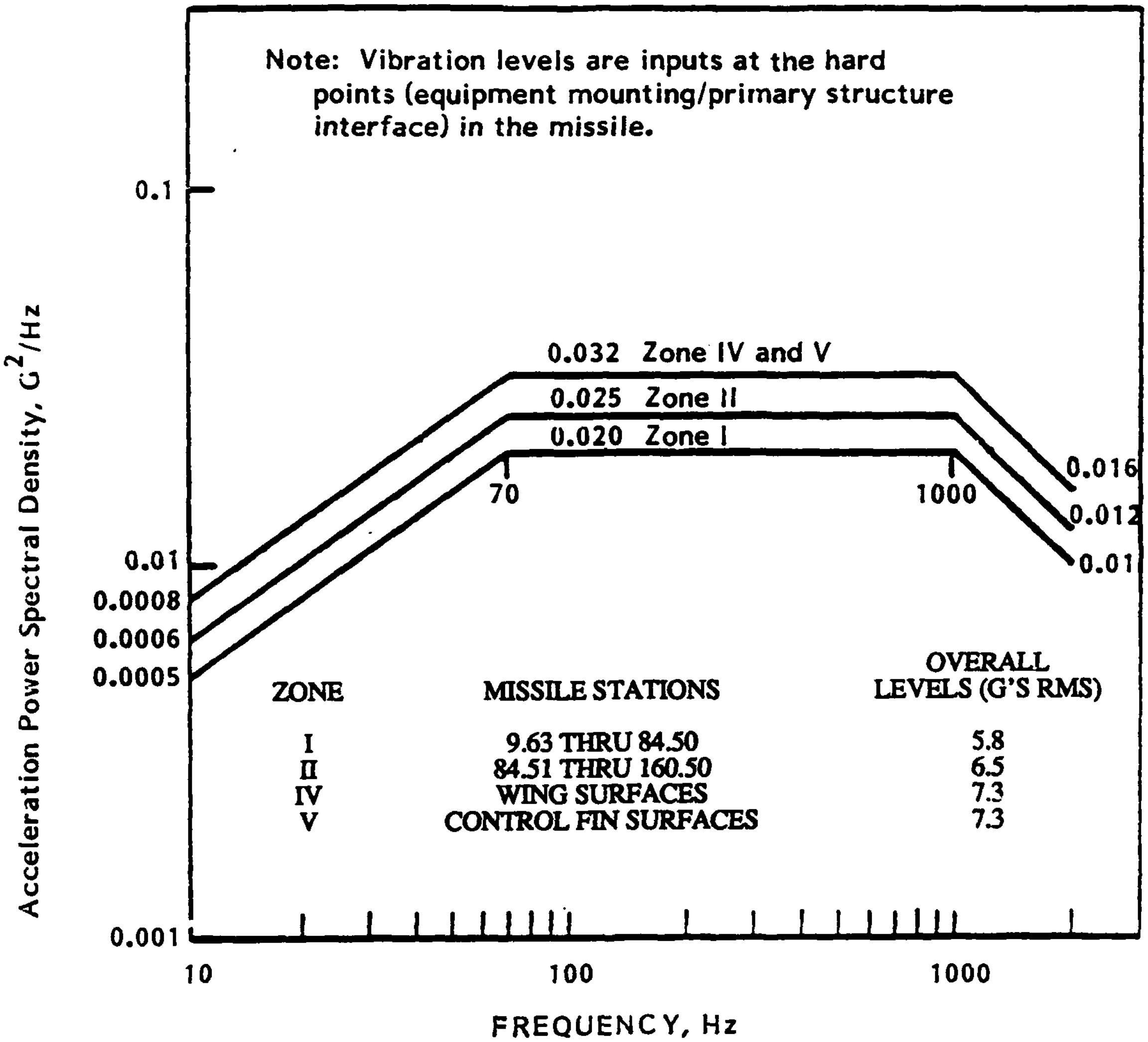


Figure 5-25 HARPOON Missile Vibration Environment, Free Flight (Sustainer) (Reference 2)

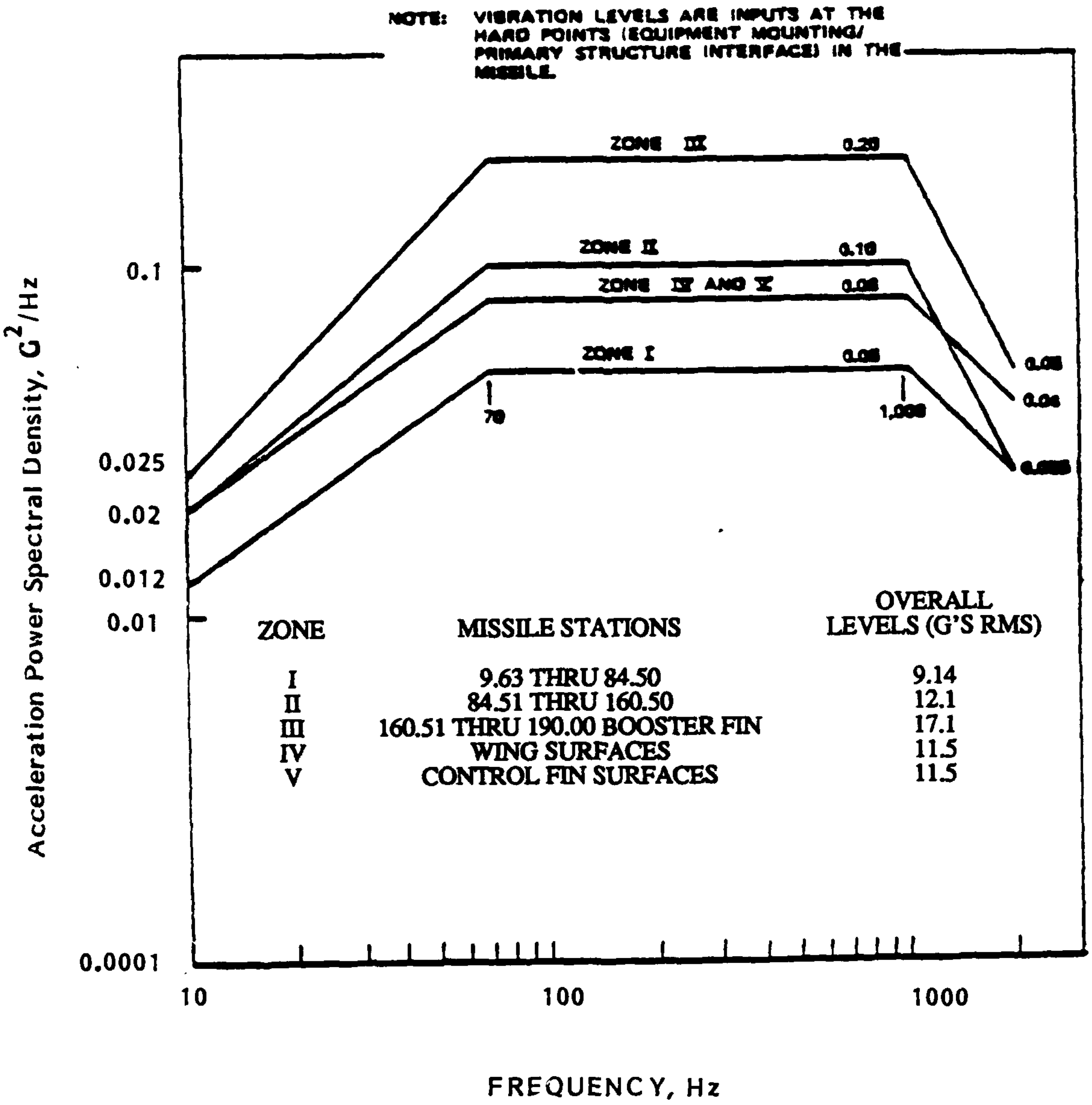


Figure 5-26 HARPOON Missile Vibration Environment, Free Flight (Boost) (Reference 2)

Vibration levels for the ship and submarine systems are given in Figures 5-27 and 5-28. The ship levels are taken directly out of Mil-Std-167 [10]. These levels are based on very old data and test equipment and are not considered representative of actual service conditions. This is especially true for large items such as for HARPOON missiles in CANISTERS on a LSS. Mil-Std-810D also refers to the Mil-Std-167 levels but gives an alternative random test level for threshold performance, Figure 514.3-34. This curve has an overall level of 0.22 g_{rms}. The submarine vibration levels are defined in terms of sinusoidal vibration in the frequency range of 5 to 500 Hz with peaks up to 10 g's, Figure 5-28. This is intended to represent the environment caused by the capsule exiting the torpedo tube and rising to the surface.

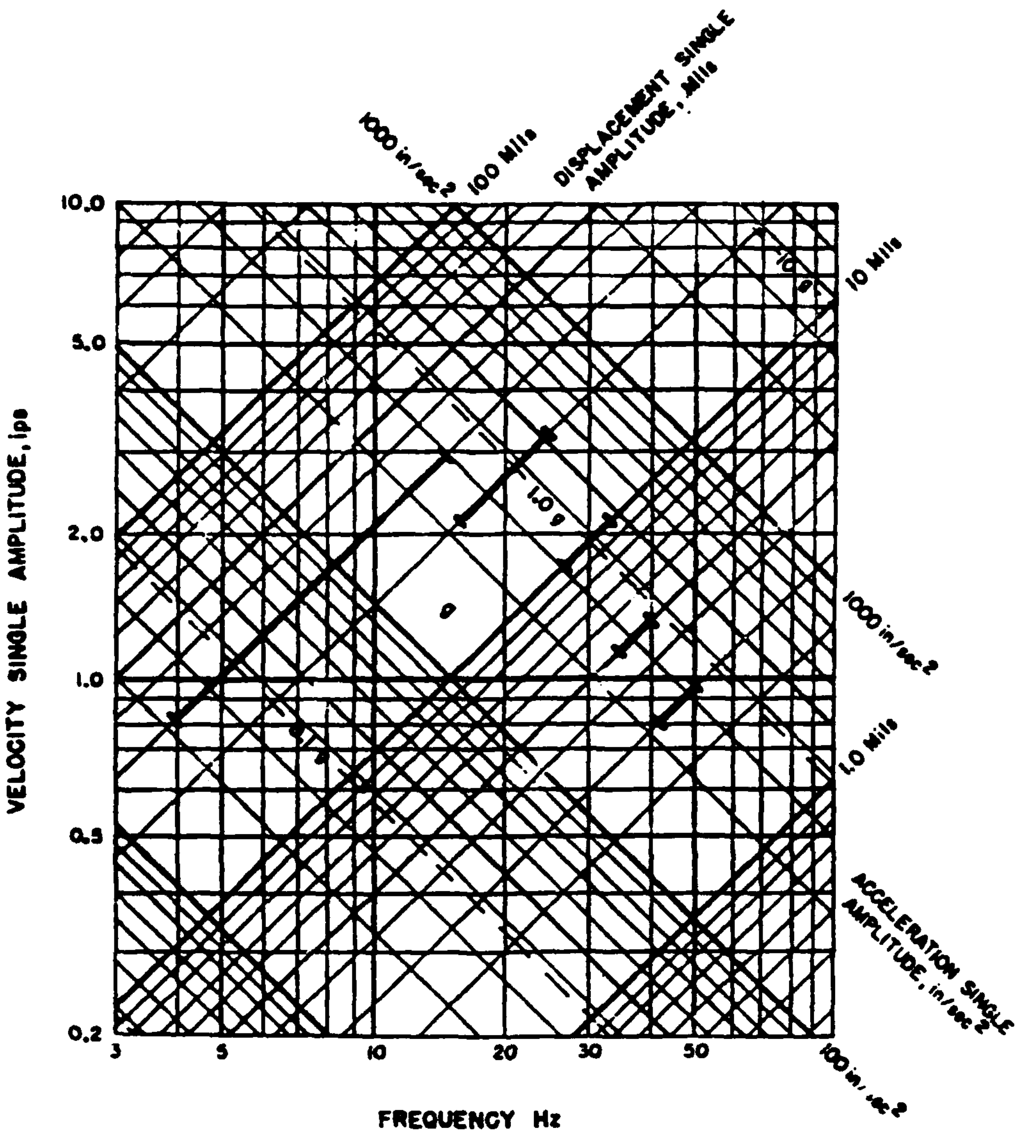
Shock levels in the air based system are primarily a result of release from the ejection rack, figure 5-29. This data appears to be derived from the results of testing performed at PMTC [21]. Since this is a platform specific level Mil-Std-810D does not have a comparable level. The levels given are said to be enveloped by a short duration pulse of 1,100 g's amplitude. Ship shock load factors, Figure 5-30, are representative of the response of the ship to various sea states. An additional shock loading present on the ship is represented by the air blast present during gunfire, Figure 5-31. The loads are defined in terms of pressure as a function of time and can result in very high acceleration levels on the test item. The final shock load, Figure 5-32, represents the exit of the missile form the torpedo tube and broaching the surface. This pulse is base on a 30 g shock pulse of approximately 25 msec duration.

The final set of data derived from Reference 2 is the acoustic levels for captive and free flight, Figures 5-33 and 5-34. The overall levels vary from 150 to 170 dB. These are similar to the levels given in Method 515.3 of Mil-Std-810D.

In general, the levels defined in XSA-2381A are similar to those given in Mil-Std-810 and therefore should be considered to be representative of the general population of military equipment. This includes the specific example given above as well as the other environmental conditions. It is apparent from the failure rates associated with the CANISTER system that something has fallen through the crack. This is one of the primary reasons for incorporating the concept of test tailoring which seeks to represent actual field data in the best possible way. To accomplish this task, we will now summarize the testing defined for various WRAs that was performed successfully.

5.2.4 Test Plans and Summary of Testing Performed

Table 1.3 defines the levels of testing for the HARPOON system. As indicated previously the DVT tests were designed to demonstrate compliance with the environmental design criteria. The other two tests, PAST and CAT, are designed to eliminate early failures due to component and manufacturing problems.



FREQUENCY, Hz	DISPLACEMENT, In.	ACCELERATION, G
	Single Amplitude	
1-4	±4.0 to 0.06	±0.1
4-15	±0.03	±0.05 to 0.69
16-25	±0.02	±0.52 to 1.28
26-33	±0.01	±0.69 to 1.11
33-40	±0.005	±0.59 to 0.82
41-50	±0.003	±0.52 to 0.77

Figure 5-27 Ship Vibration (Ref. Mil-Std-167B) (References 2 and 10)

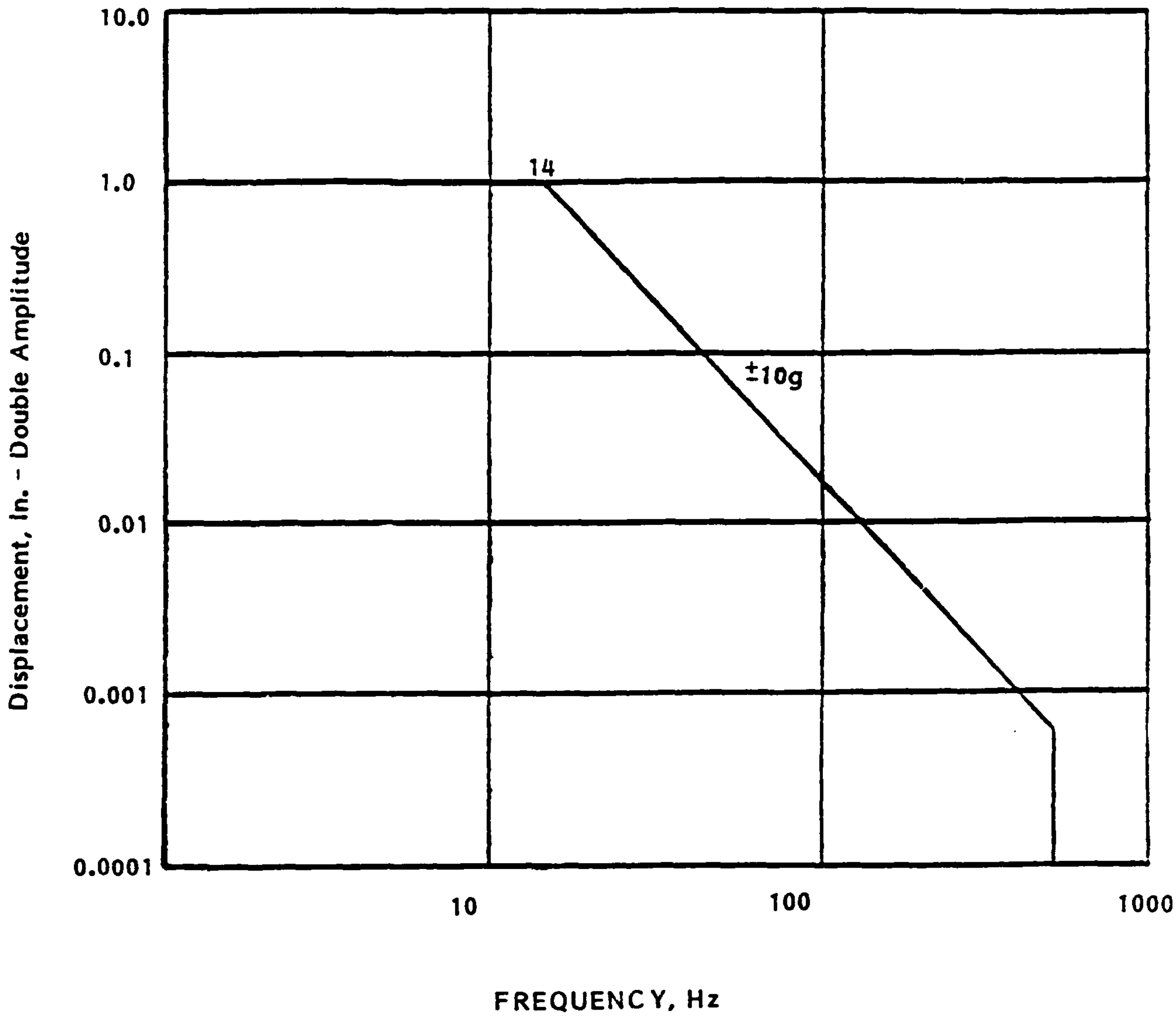
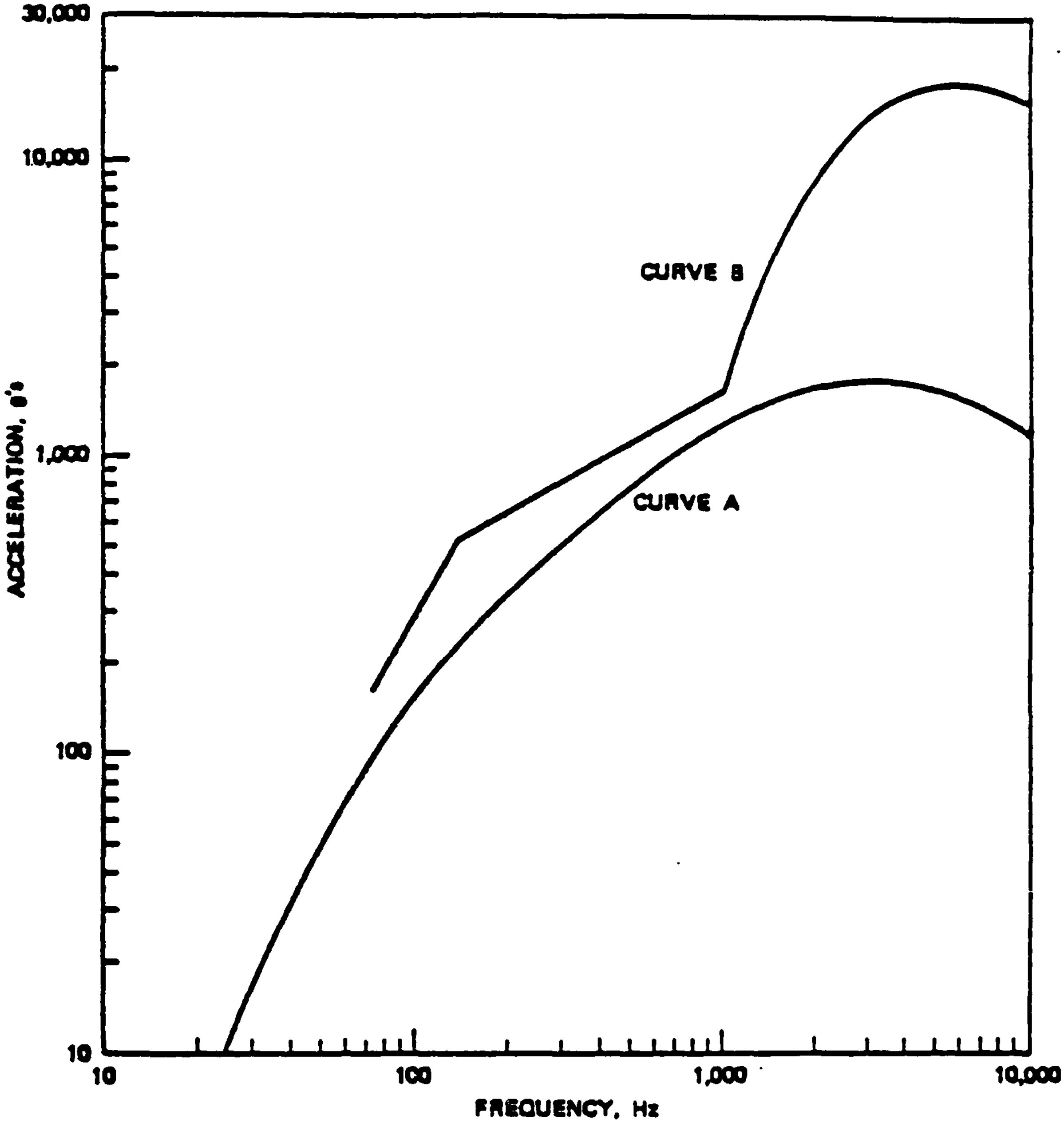


Figure 5-28 Submarine to Surface Induced Sinuso[illegible]l Vibration (Reference 2)



CURVE A – EJECTION RACK AND PROBE ERECTION SHOCK SPECTRUM – CAN BE OBTAINED FROM A HALF SINE PULSE WITH AN AMPLITUDE OF 1100 g's PEAK AND A DURATION OF 0.5 MILLISECONDS

CURVE B – BOOSTER CLAMP RING SHOCK SPECTRUM

Figure 5-29 HARPOON Missile Ejection Rack and Probe Erection, Booster Clamp Ring Shock Spectrum (Reference 2)

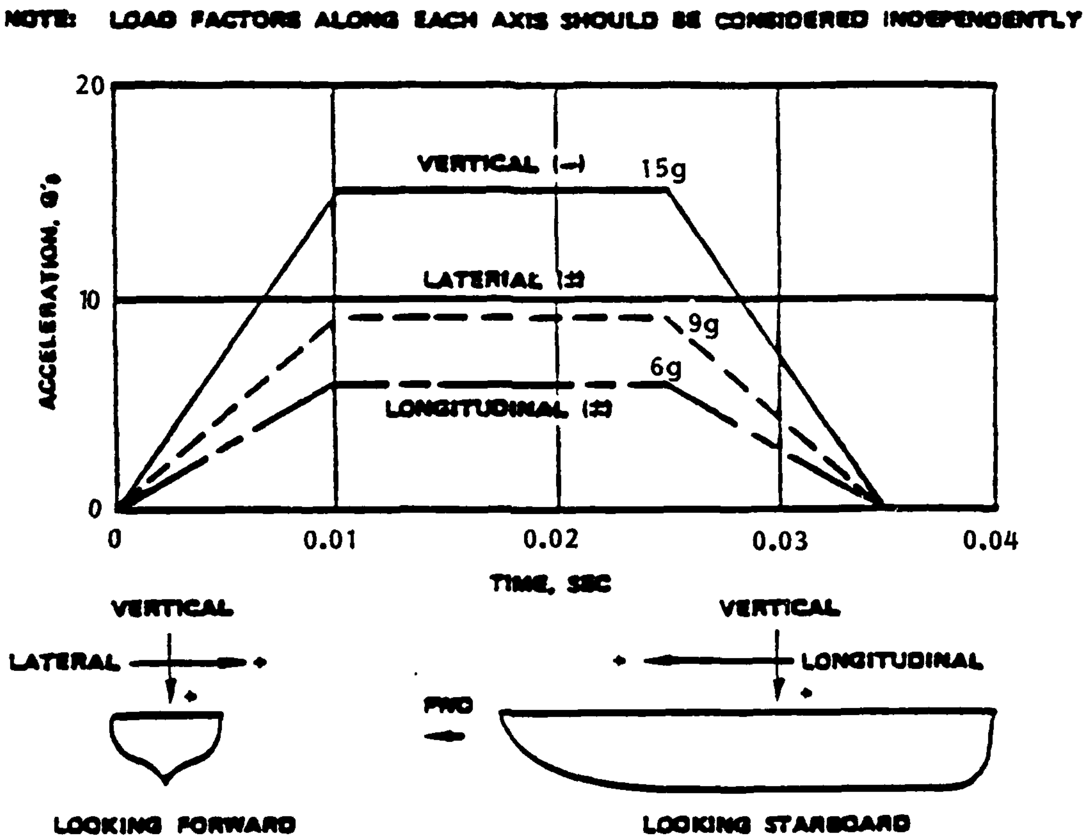


Figure 5-30 Ship Shock Load Factors vs Time (Reference 2)

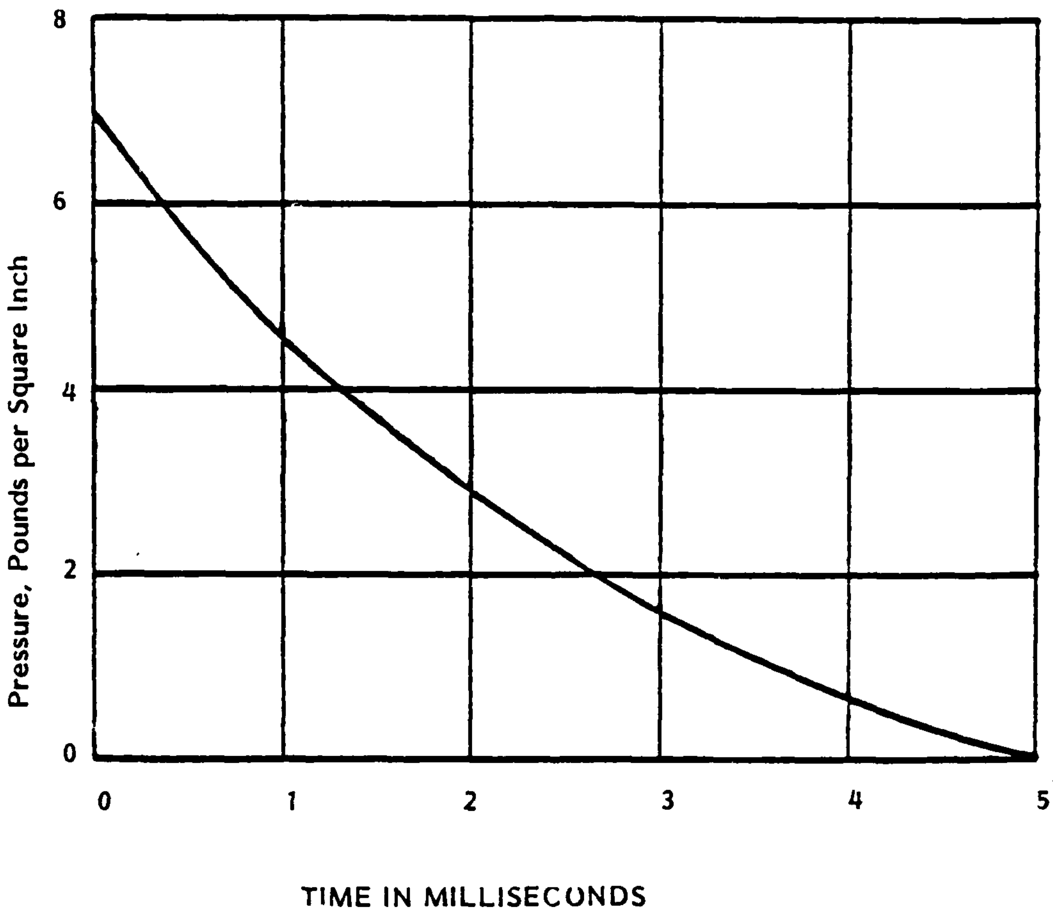


Figure 5-31 Shock Pulse from Gun Blast (Reference 2)

Encapsulated HARPOON Shock Spectrum

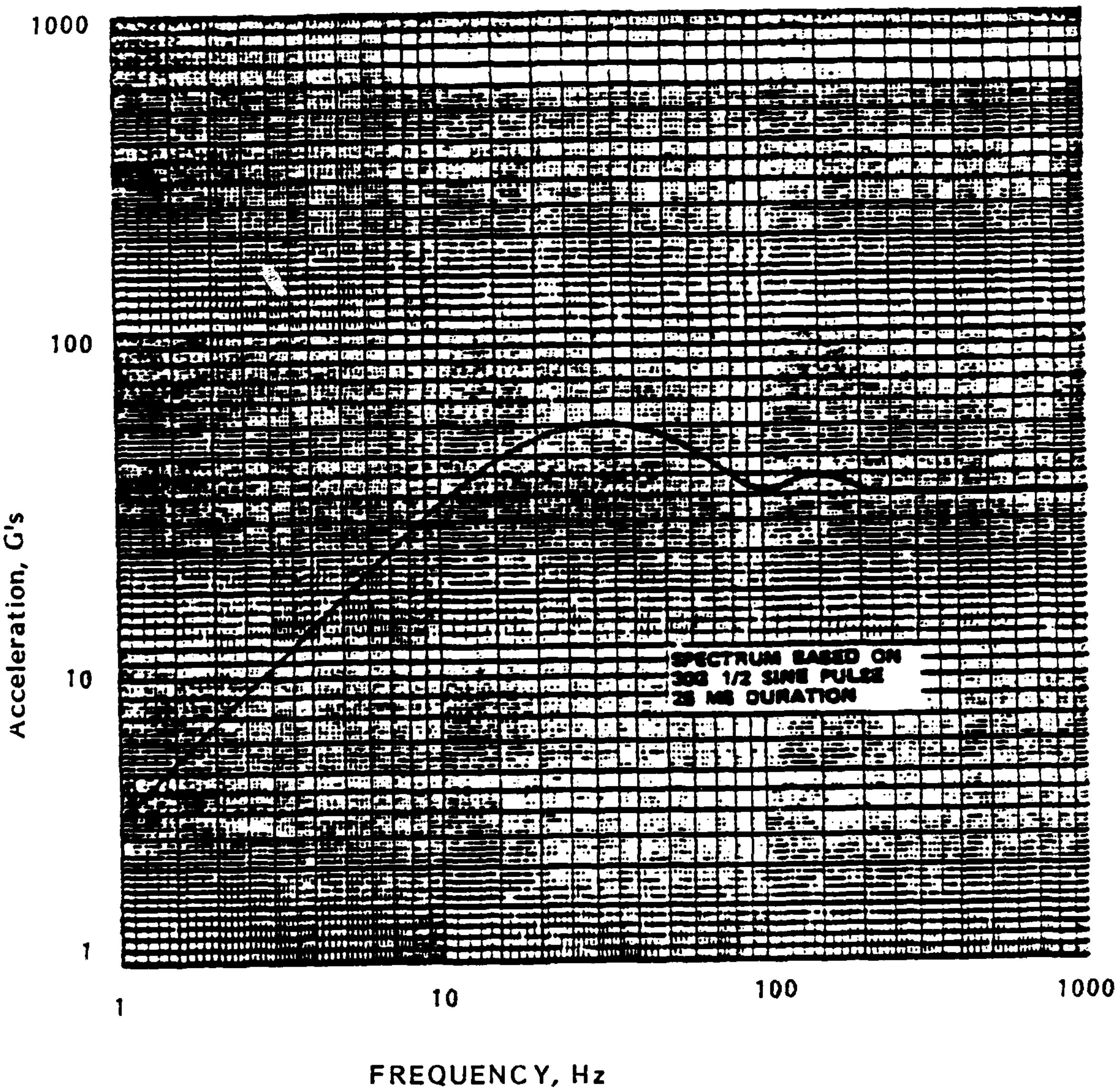


Figure 5-32 Submarine-to-Surface (Reference 2)

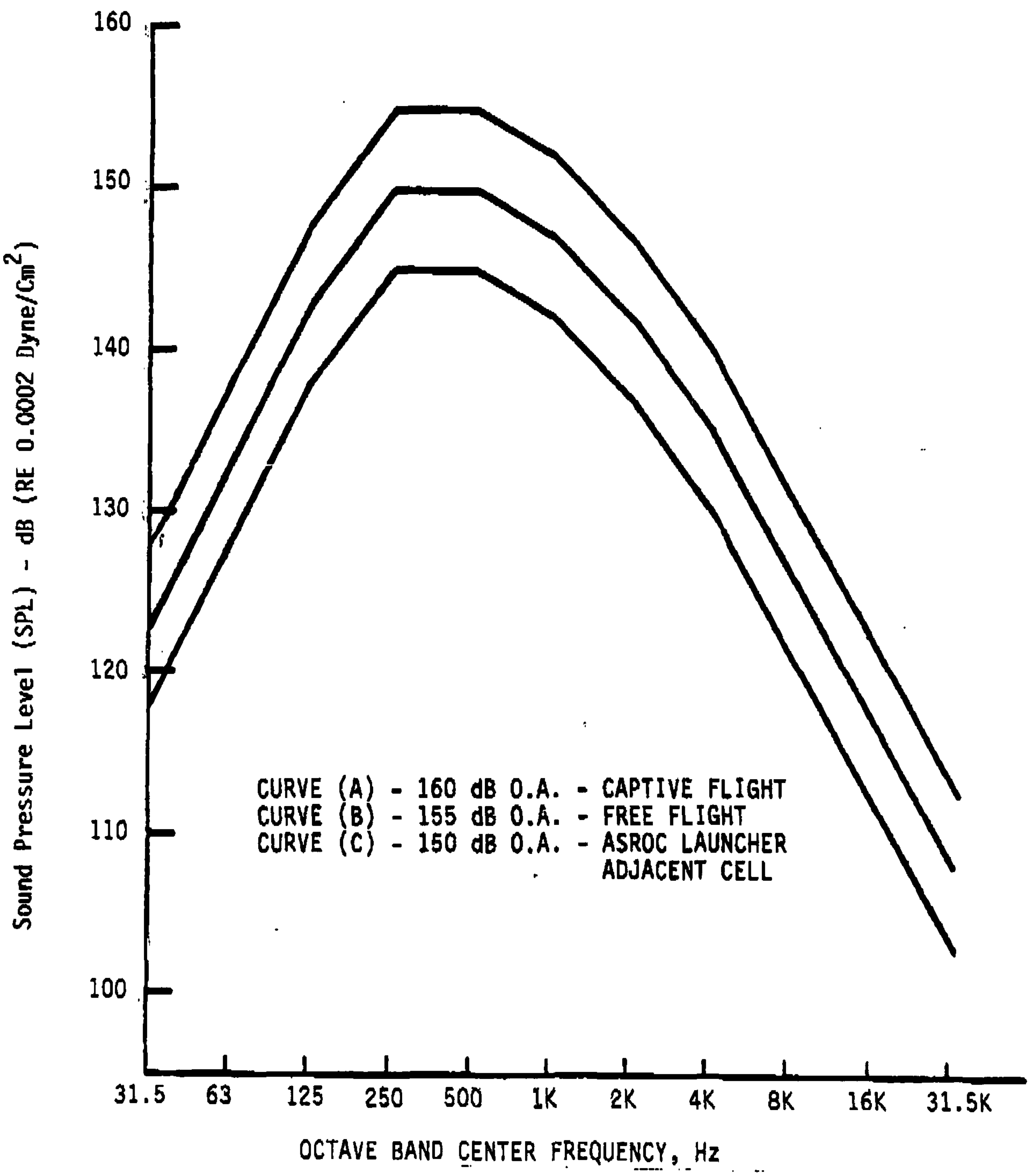


Figure 5-33 HARPOON Missile External Acoustic Levels (Reference 2)

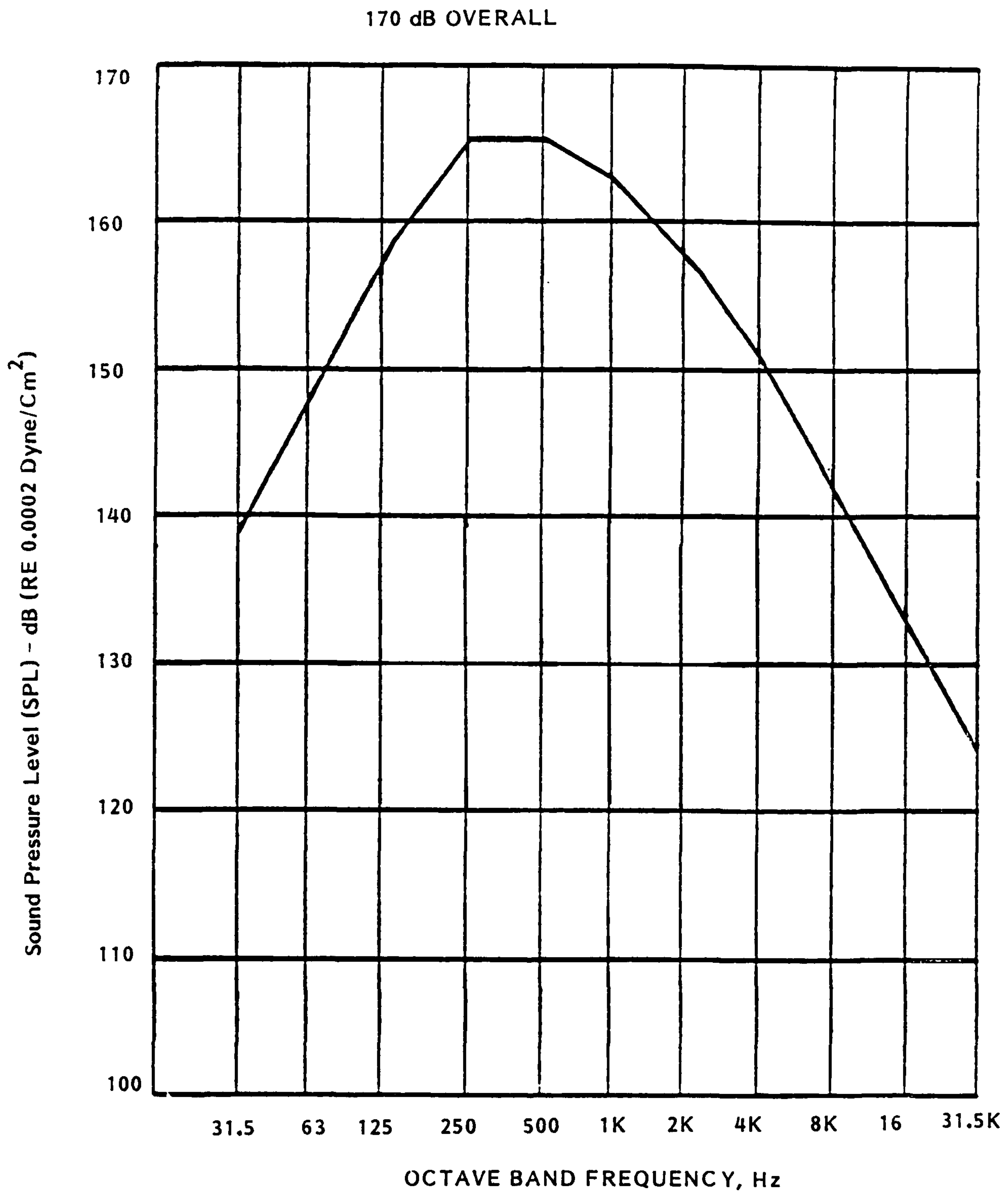


Figure 5-34 HARPOON Missile Boost Flight External Acoustic Levels (Reference 2)

Information on what types of qualification testing have been performed on the HARPOON, in terms of WRA's or the total system, is difficult to obtain. Data reviewed by SwRI is limited to reports on Container testing, copies of presentations and a review made by PMTC personnel. There are several documents available on measurement of field data, but these should not be considered qualification tests since functionality of the items was not measured. The information presented in this report contains information made available to SwRI, and therefore may not represent the complete set of data.

We will first look at qualification testing performed on the system and some details of testing on specific WRA's. Since the major failure problem is associated with the CANISTER version of the missile the emphasis will be on that platform.

References 22 and 23 indicate that the following tests have been performed on the HARPOON missile. A general discussion of the results of this testing is contained in these references, but no detailed study of the test reports was possible. It was also not possible to obtain any details of the levels of environmental conditions to which the test items were exposed from the literature reviewed. Some information can be drawn from the description of the military standard or document covering the testing. The following groups of testing have been performed as defined by References 22 and 23:

Desert Exposure (NWC/CL). No significant environmental induced anomalies occurred as a result of these tests. Missile LO 45 Passed MSTS. Missile LO 92 Failed, Mid-Course Guidance.
Restrained Firing (NSWSES/White Sands). Missile LO 66 Failed, Altimeter. Missile LO 89 Failed, Altimeter.
Diagnostic Testing (Wyle/Norco). Fungus, Salt Fog, Ice, Rain. Missile LO 42 Failed, Seeker. Missile LO 48 Failed, Seeker.
1975 At PMTC. Ship storage vibration. Missile handling shock. Acoustics. Aircraft ejection. Fungus/humidity/salt fog. Sand and dust. Ship gunfire. Aircraft carry temperature/pressure/vibration. Free flight temperature/vibration. Shipboard shock (Not 901-C).

1976 ASROC Shipboard (DE-1052). Vibration. Gunfire.
1977-78 Section combined environment (Guidance, Sustainer, and Control). Cold temperature, sine vibration and repetitive shock. Tested 21 Guidance, 10 Sustainer and 24 Control Sections. Discontinued as not a cost effective screen.
1978 Grade B Canisters and LSS (AETL/SAUGUS). Shipboard vibration (Mil-Std-167). Produced numerous anomalies. Primary. Structural locking features. Secondary. Canister rail. Electrical wiring/connector. Seeker. Input considered excessive and unsymmetrical, probably due to large mass (12,000 lbs). Conclusions was that test was NOT representative since similar anomalies had not been observed in fleet operations. Missile LO 66 Failed, Seeker and Altimeter. Missile LO 89 Failed, Seeker. Missile LO 42 Failed, Seeker. Missile LO 48 Passed MSTS.
1979 Underwater Shock (Mil-S-901C) (SENSY, Hunters Point). Grade B CANISTERS and LSS successfully completed test showing the safe (Grade B) and operational. (Grade A) capability.

The desert exposure testing at China Lake was limited to exposure to natural conditions of high temperature in a simulated storage condition. The indicated results are that no significant environmental anomalies concurred as a result of these tests although Missile LO 95 had an indicated failure in the Mid-Course Guidance section. This discrepancy needs to be clarified.

During the restrained firing testing at White Sands, failures were noted in both the altimeters. There is no explanation of the nature of the problem or any indication of what corrective action was taken to prevent its reoccurrence. Similar results were obtained in the diagnostic testing at Wyle Laboratories, where the seeker failed. Again no explanation or corrective action is given.

For the testing at PMTC in 1975 and the shipboard testing of the ASROC configuration there is no indication of the actual testing performed or the results. These groups of tests contain significant information that could give an indication of the susceptibility of the missile to some of the environments assumed to cause the high failure rates of the shipboard configuration. These include: acoustics, ship gunfire, aircraft carry temperature/pressure/vibration, free flight temperature/vibration, shipboard shock, vibration and gunfire. It would be useful to review the level of testing performed and the results including any anomalies.

The combined environment testing on the guidance, sustainer and control sections appears to be an attempt to perform environmental stress screening (ESS) of the items. It is not apparent if these tests were designed to indicate workmanship or manufacturing problems or susceptibility to service environments. The ESS may have been done at such low levels that it may not have initiated any failures.

The attempt to perform Mil-Std-167 testing at AETL on the LSS system with four missiles installed had significant problems. The first was that the equipment utilized to induce the vibration was not large enough to limit test item interaction with the inputs. In addition, to have enough force capacity to push the test item, the equipment must be massive enough and have sufficient resistance to overturning moment to limit test item interaction with the input. For an estimated weight of 12,000 lbs, a center of gravity 80 inches from the base, an input level of one g and a dynamic amplification factor of 10, the moment that needs to be resisted is approximately 800,000 ft-lbs, a significant number. All indications are that the levels input into the LSS were not as defined in Mil-Std-167.

There were a number of anomalies noted during the testing, failure of the seeker on three of the four missiles as well as failure on the altimeter on one of the missiles. Although the inputs were not in accordance with the test requirements, these results should have drawn attention to the fact that the seeker was a weak link in the system. Although this fact is brought out in the references, it is not apparent what corrective action was taken. Reference 24 contains some additional details of the results of the testing at AETL not covered in References 22 and 23.

A final comment on this test is that Mil-Std-167 test requirements are based on a significant amount of historical data. This requirement was established when the majority of test equipment was limited to sinusoidal excitation. Current knowledge indicates that random testing, wether it be narrow or broad band, is a more appropriate excitation. In addition the standard is oriented to the testing of smaller test items. The author is of the opinion that for a test item of this size it is necessary to tailor the vibration levels to simulated service conditions. Without tailoring, it is difficult, if not impossible, to develop a system to withstand the severe test vibration levels.

The final group of tests indicate that the CANISTER system passed an underwater test sequence in accordance with Mil-S-901C.

Since References 22 and 23 were produced, other testing has been performed on the HARPOON system [5 to 9 and 11]. With the exception of the USS Mississippi testing, all these tests were performed on dynamic simulators or dummies. Because of this it was not possible to check the functionality of the missile as a result of the testing. During the USS Mississippi testing five of the seven missiles failed the post test MSTS. Of these five, two were not tested prior to the shipboard program. Of the other three remaining failures, two were in the seeker and one was in the ARA. It should be noted, with the exception of the gunfire, the levels of vibration and shock during the sea trials were benign. Sea states were very calm during the entire test program.

The vast majority of the testing described above was performed on the complete missile or a group of missiles. A significant level of effort has gone into performing this testing. With the data available to SwRI, it is not possible to determine if the levels of testing performed on the missiles themselves or the various launch platforms was in conformance with the requirements. It is also not evident what tests the missiles have successfully completed.

It is now appropriate to discuss in some detail the defined test requirements for WRA's. Documentation is available giving a general description of the testing required [25 to 31] although no detailed test plans were reviewed. It is apparent from a review of the documentation list in the ORI library [14] that a significant number of documents exist covering testing at this level. Only those listed were partially reviewed, due to limited time and access. The following is a listing of the test levels defined for eight WRA's:

Qualification/Design Verification Tests (DVT)	
a)	Seeker [25] Random Vibration - 7.6 g_{rms}, 10 sec/axis, non-operating 5.4 g_{rms}, 30 min/axis, operating Sine Vibration - 53.2 mins/3 axis Shock - 45 g's, 15 msec, 6 shocks, non-operating 30 g's, 15 msec, 6 shocks, operating Temperature/Humidity - 4 cycles, Figure 5-35
b)	Probe/Crush Sensor Mil-P-85459 Random Vibration - 5.8 g_{rms}, 10 min/axis, erect, Figure 5-36 5.8 g_{rms}, 2 hrs/axis, non-erect 9.2 g_{rms}, 1 min/axis, boost Shock - 15 g's, 20 to 1.50 msec Temperature/Humidity - 2 cycles, Figure 5-35

Qualification/Design Verification Tests (DVT) - Continued	
c)	Electronic Equipment [27] Random Vibration - 5.8 g_{rms}, 1 min/axis, non-operating, Figure 5-36 12.9, 17.1 or 24.2 g_{rms}, 10 sec/axis, operating 8.2 or 9.2 g_{rms}, 30 min/axis, operating Sine Vibration and Sine Dwells 30 - min/resonance, non-operating Sine Sweeps - 2 hours/axis total with dwells Acoustic - 158 db for 1 min, operating 148 db for 29 min, non-operating Shock - 42 g's, 25 msec rise time, non-operating 27 g's, 25 msec rise time, operating 1100 g's, 0.5 msec duration, pyro Temperature/Humidity -65°F and 170°F for 1 hr each, non-operating 170°F with altitude for 1 hour
d)	Midcourse Guidance Unit (MGU) [28] Random Vibration - 8.2 g_{rms}, 30 min/axis, non-operating and operational 12.9 g_{rms}, 10 sec/axis, operational 5.8 g_{rms}, 10 min/axis, operational, Figure 5-36 1.1 g_{rms}, 5 min/axis, gyro operational Sine Vibration Sine Dwells - 30 min/resonance, non-operating Sine Sweeps - 2 hours/axis total with dwells Acoustic - 150 db, operating 168 db for 30 min, operational and non-operating Shock - 27 g's, 25 msec rise time, operating 385 g's, 0.5 msec duration, pyro Temperature/Humidity -40°F and 160°F, non-operating -60°F minimum one hour, operate for at least 10 min, 170°F non-operating and operating 68°F to 100°F non-operating humidity
e)	Digital Computer with Power Supply [29] Sine Vibration - 20 to 60 hz, 3 min Temperature/Humidity 7 cycles -50°F and 130°F, 2 hours, non-operating
f)	Attitude Reference Assembly (ARA) [30] Sine Vibration - 5.2 g's, 30 to 60 hz, 1.5 minutes Temperature/Humidity 7 cycles, -60°F and 150°F, 1 hour
g)	Radar Seeker [31] Random Vibration 5.46 g_{rms}, 30 min/axis, operating 7.6 g_{rms}, 10 sec/axis, non-operating Sine Vibration 53.2 min/axis Shock Temperature/Humidity
h)	Altimeter with Power Converter [32] Random Vibration - 12.9 g_{rms}, 10 sec/axis, operating 8.2 g_{rms}, 30 min/axis, operating Sine Vibration - 2 hrs/axis, non-operating Shock - 27 g's, 25 msec rise time, 6 shocks, operating 1100 g's, 0.5 msec duration Temperature/Humidity

Pre-Acceptance Screening Tests (PAST) [26]	
a)	Seeker Temperature Cycling - 1 cycle -65°F to 170°F 5 cycles -65°F to 120°F Random Vibration - 4.1 g_{rms}, 5 min/axis, Figure 5-36
c)	Electronic Equipment Temperature Cycling - 4 cycles -65°F to 170°F Random Vibration - 5.8 g_{rms}, 5 min/axis, Figure 5-36
e)	Digital Computer/Power Supply Temperature Cycling - 4 cycles -60°F to 150°F Random Vibration - 5.8 g_{rms}, 5 min/axis, Figure 5-36
f)	Attitude Reference Assembly Temperature Cycling - 4 cycles -60°F to 150°F Random Vibration - 5.8 g_{rms}, 5 min/axis, Figure 5-36
g)	Altimeter Temperature Cycling - 8 cycles -65°F to 160°F Random Vibration - 5.8 g_{rms}, 1 min/axis, Figure 5-36

Customer Acceptance Tests (CAT) [26]	
a)	Seeker Temperature Cycling - 1 cycle -65°F to 170°F 3 cycles -65°F to 120°F All cycles failure free.
c)	Electronic Equipment Temperature Cycling - 3 cycles -65°F to 170°F All cycles failure free.
d)	Midcourse Guidance Unit Temperature Cycling - 1 cycle -60°F to 150°F Failure free. Random Vibration - 2.5 g_{rms}, 3 min/axis, Figure 5-36
e)	Digital Computer/Power Supply Temperature Cycling - 3 cycles -60°F to 130°F All cycles failure free.
f)	Attitude Reference Assembly Temperature Cycling - 3 cycles -60°F to 150°F All cycles failure free. Sinusoidal Vibration - 5.2 g's peak at a single frequency between 30 and 60 Hz for 1.5 minutes during each temperature cycle.
h)	Altimeter Temperature Cycling - 4 cycles -65°F to 160°F All cycles failure free.

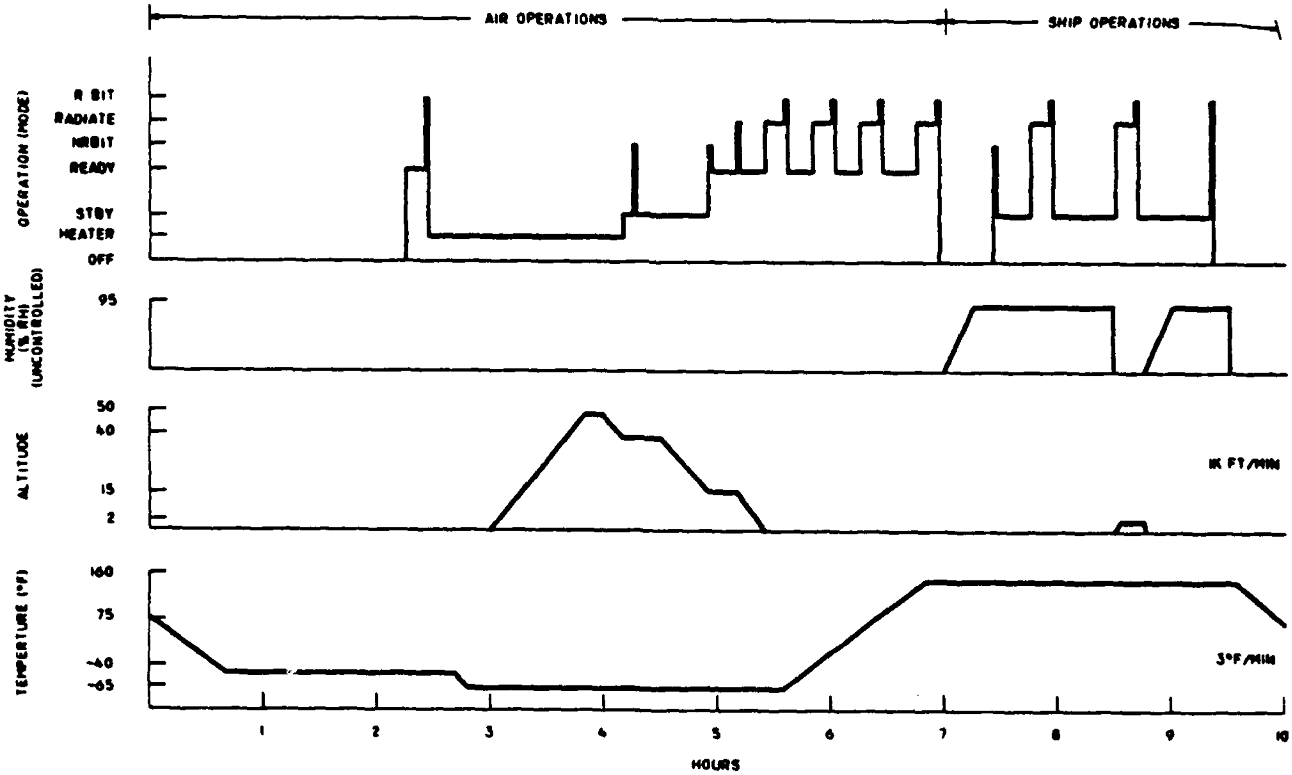


Figure 5-35 Combined Temperature/Altitude/Humidity Test Profile (Reference 25)

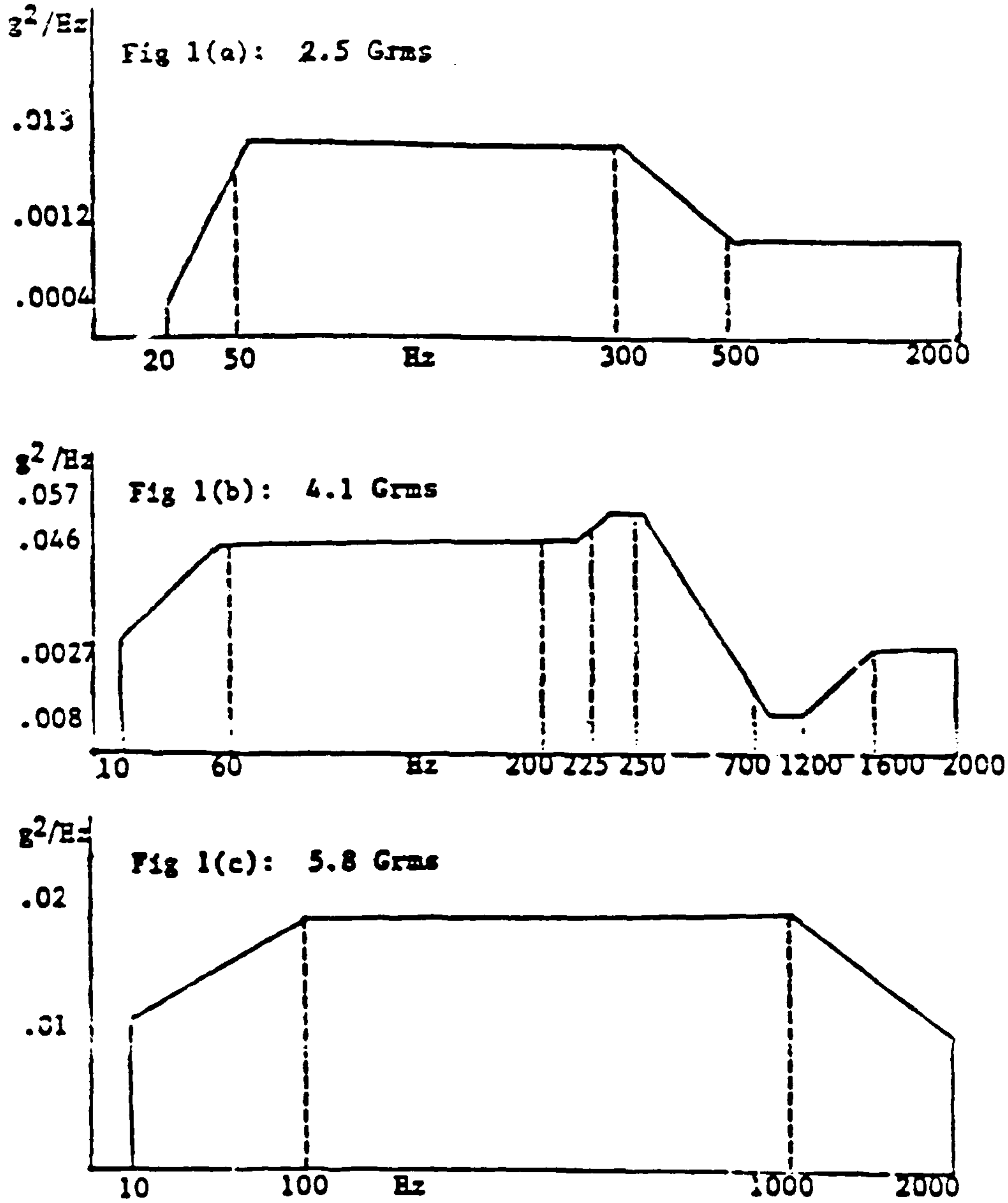


Figure 5-36 Vibration Spectrums (Reference 26)

There are several general points to note concerning the information presented. The first is that not all WRA's are subjected to testing at all three levels. For example, the MGU is not subjected to the PAST testing. There is no apparent reason for the selection of which units are tested at which levels. It is possible that the missing tests are defined in documentation not reviewed by SwRI or they are tested at a higher level of assembly.

Another point is that the ranges for temperature cycling within a group varies with the WRA. In the CAT testing, the high temperature limit varies from 130°F to 170°F. It was not possible to determine if this variation was due to measured differences in the service conditions, or if the levels were adjusted to meet the capabilities of the individual WRA's.

There are similar discrepancies in the levels of the shock and vibration testing. In some instances shock testing is designed to simulate handling, operational and pyrotechnic conditions for the electronic equipment during DVT testing. It is completely left out for other WRA's (Digital Computer and Attitude Reference Assembly). It is logical that the vibration levels vary since differences have been measured during field and laboratory testing. This is especially true for the DVT tests which are designed to show susceptibility and tailoring is appropriate.

It is now appropriate to look at data on the results of testing performed on the WRA's. The results presented in this report are derived from information suppled to SwRI by PMTC personnel. No additional study of available literature was performed. Information was available only on the Midcourse Guidance Unit, the Attitude Reference Assembly and the Altimeter. It was not possible to obtain any information on the Seeker, the item that displays a high failure rate during testing and in service.

Information indicates that the MGU was qualified on two occasions, in 1974 and again in 1982. The first sequence of testing included:

Random Vibration
Sine Vibration
Pyro Shock
Humidity
Temperature/Altitude

All tests correspond to the DVT testing outlined above with the exception that acoustic testing was not performed. Anomalies were noted during the testing. These included loss of C9 from the I/O page and receptive intermittent functioning during sine vibration testing. Changes to the design to alleviate these two problems are indicated although no repeat of the testing is given. Humidity testing induced a number anomalies including capacitor problems, substrate short on the memory module, lack of conforming coating and micro-circuit failure. It is not apparent what action items were initiated and followed through as a result of this testing. The second qualification on the MGU was in 1982. It is interesting to note that qualification to Humidity was by similarity, although the initial series of tests had problems and no subsequent retests are indicated.

The Attitude Reference Assembly (ARA) was tested by Northrup in 1975 and by LSI in 1979. The extent of the testing performed was not indicated. In the Northrup testing the ARA had to be dried at 150°F for a period of 36 hours following the humidity testing to pass the functional checks. During the LSI testing no humidity testing was performed. Anomalies were indicated in these tests with several attempts at modifications and retests. It is not apparent if the item finally passed a complete set of tests.

A number of qualification programs were performed on the Altimeter. The Kollsman Altimeter was subject to at least two sequences of tests; Phase I in 1982 and Phase II in 1984. During the Phase I testing problems were encountered during the random vibration, humidity and temperature/altitude tests. During the vibration testing the leads on a power supply filter capacitor broke and a FET shorted. To alleviate the first problem the parts were purged from the stock. No cause or action item for the second problem was indicated.

During the humidity testing of the Kollsman Altimeter, 10 cycles of 95% RH at 149°F for 8 hours and 85% RH at 86°F for 16 hours, gross anomalies were noted in the capacitors. Production stock testing indicated a 100% failure rate. The items were purged from the stock and subsequent purchases limited to tested and approved parts. During the temperature/altitude testing problems were indicated in a solder joint and an attachment screw. Procedures were adopted for proper soldering and torquing screws.

The recommendations of Phase I was to develop a Phase II qualification program to include temperature, vibration and shock. It is not apparent why humidity was left out of this Phase II program. During the Phase II random vibration testing a buss wire broke, capacitor leads broke and solder joints fractured. Fixes were outlined to alleviate subsequent failures. Multiple anomalies were noted at 170°F with various fixes.

Honeywell tested both the HARPOON Missile Radar Altimeter (HMRA) and the Cruise Missile Radar Altimeter (CMRA). The first sequence was the CMRA and included the following testing;

Ground Handling and Transportation Shock
Ground Handling and Transportation Vibration
Sine Vibration
Captive Carry Vibration

Free Flight Vibration
Acoustics
Launch Ejection

A number of anomalies were noted during the test sequence. The first was a problem with resistor R29 that resulted in an anomaly associated with the indicated altitude requirements. During testing, measurements were consistently below the requirements and a request for deviation down to a lower level was made to "allow the unit to pass with the new requirement". During the captive and free flight vibration, a broken wire at the base of transistor Q1 and an intermittent failure of the IF connector pin was noted. Changes in the construction and quality assurance procedures were made to eliminate these problems. During the launch ejection testing an isolator load resistor detached resulting in a failure of the far range sensitivity. It was determined that an overtest was performed but no retest was indicated. Additional problems were found in the selection for R77 and R79 with changes made to procedures to alleviate the problems. Additional environmental conditions were qualified by analysis. These included dust, acceleration, explosive atmosphere, launch ejection, submunitions ejection shock, catapult and trap shock, salt fog, boost vibration, ground handling and transportation vibration and fungus.

For the testing of HMRA in 1985, sine and random vibration, operational shock, temperature cycling and bench handling shock are included in the test plan. It is not clear what tests were actually performed. Qualification by similarity to the CMRA is given for pyro shock, non-operating shock, handling and transportation shock, acoustics and humidity. It is interesting to note that anomalies had occurred during the testing of the CMRA, and although corrective actions are indicated there is no evidence of retest. In addition it was not possible to find any information of the results of the pyro shock and humidity testing of the CMRA.

As with the testing of the entire missile and its various platforms, a number of anomalies were indicated during the testing sequence for the ᵛ⁻ There are indications that corrective action items were initiated for a majority of these anomalies. It is not apparent if the item was retested with these fixed, incorporated to determine if the problem was actually fixed. There appears to be a significant amount of qualification by similarity where the original item did not pass the testing or no indication of testing is available.

It is important to reiterate that the information present in this report is based on the information supplied to SwRI for review. From a review of the documentation in the ORI library [14] it is apparent that more information is available. Due to time and cost constraints, it was not possible to review all the data. It is appropriate to update the information presented in this report to obtain a more complete picture of the status of the HARPOON qualification testing.

5.3 Captive Carry Platform Characteristics

It has been recognized that the three platforms for deployment have significantly different environments [2]. Parameters such as temperature extremes (with the exception of aerodynamic heating), humidity, rain, salt fog, sand and dust and ice and freezing rain are driven primarily by natural conditions. The location of the platform; on the land, sea or air, and the world climatic region are controlling factors. The basic levels are defined in Mil-Std-210C and Mil-Std-810D and are applicable in most instances. There may be some modifications depending upon the type of protection offered by the various platforms, as defined previously.

The induced environments: including temperature, vibration, acoustics, shock, and acceleration, are driven primarily by platform characteristics. We will look at some details for these environments since they seem to be a factor in the failure rate of the missile in service.

5.3.1 Air Based

Hall [33] refers to a study that gives conclusive evidence "that environments are responsible for 52% of the avionics field failures, with 90% of environment related failures attributed to temperature, altitude, humidity and vibration." These results are based on analysis of data on failures of a wide range of avionic components. In addition to extreme conditions that may cause immediate stress overload failures fatigue may be a problem. "...it was found that the presence of very low amplitude vibration for a long period of time does have a significant impact on equipment life." It is therefore necessary to look at both the levels and duration of the exposure conditions.

Thermal extremes are the result of the basic air temperature, variations in flight altitude and the potential for aerodynamic heating during high speed flight. In addition to thermal stress and temperature effects on the material properties, this variation in temperature can result in condensation of moisture in the air due to thermal lag between the components of the missile and the surrounding air. Each of these conditions can lead to failure of the missile. In captive flight, low temperature are experienced during long duration cruise or maximum endurance flight at high altitude [34]. Extreme flight conditions of this nature can cold soak a weapon to levels that will cause performance problems with such components as electronics, thermal batteries, propellant trains and fuel systems. Maximum skin temperatures in captive flight occurs during a supersonic dash, and maximum internal temperatures can be caused by long duration flights a low altitude and high supersonic speeds. Thermal problems associated with hot captive flight profiles generally involve exceeding the temperature limitation of internal electronic components, explosives, and solid or liquid fuels. The storage and preflight climatic condition is not considered and could cause deterioration of systems prior to use if long-term temperatures were excessive.

The major components of the air based dynamic environments are the performance parameters of the aircraft, the dynamics of the aircraft and missile and their interaction on the pylon. A significant amount of information exists on the vibration levels of stores on aircraft. A large number of variables are involved in this data base, including the type of aircraft, pylon and missile. We will limit our discussion as much a possible to information specifically on the HARPOON. Typical low frequency response of the HARPOON on the wing of an A-6E aircraft are:

First Modes of the HARPOON on the A-6E Aircraft (analysis from Grumman)

Frequency	Description
9.41 hz	HARPOON Yaw
10.32 hz	HARPOON Lateral
12.37 hz	HARPOON Pitch

These represent missile responses. Additional low frequency dynamic response will be driven by the influence of the missile on the dynamics of the aircraft wing and fuselage.

The missile is also subjected to high frequency buffeting resulting in vibration and acoustic excitation. Studies [35] have shown conclusively that the major source of stimulation of the vibration and acoustic loads on a missile during captive carry is the aerodynamic boundary layer operating upon the total skin area of the missile. This excitation is drive by air flow around the geometry of the missile, aircraft and interface and is a function primarily of the dynamic pressure during flight. Broadband response spectra for captive carry conditions will be colored by low frequency characteristics arising from aircraft, pylon/launcher attachments and missile body bending/cylindrical modes. Typical captive carry life requirements include 90% of the time at cruise and 10% at high-speed low-altitude flight conditions, supplemented by maneuvers and transients.

The random vibration and acoustic data is normally presented in terms of a power spectral density (PSD). This gives the energy content of the vibration and acoustics as a function of frequency A single value giving the overall level is the g_{rms}, defined as a statistically determined 95th percentile with 50% confidence value based on a one-sided tolerance limit [36].

Recent work by Allen [36] has looked at developing a realistic model of the environmental stresses on external stores for various configurations and flight conditions. One of stores in the program was the HARPOON (AGM-84), with a total of 635 measurements for this missile. The g_{rms} as a function of the dynamic pressure (q) is summarized in Figure 5-37 and Table 5.10. Based on a maximum q of 1200 lb/ft^2, the maximum defined in Mil-Std-810D, the overall g_{rms} is 6.2 g_{rms}. This is comparable to the 5.8 g_{rms} given in Figure 5-24 from XAS-2381A. The minimum level is defined as 1.3 g_{rms} for q less than 250 lb/ft^2. During a normal mission the level will vary between these two extremes.

To develop a single test level it is necessary to scale the various in-service levels to a common one. Time compression is related to the stress factor (S), in this case assumed to be g_{rms}, by:

$$\frac{S_s}{S_t} = \left(\frac{T_s}{T_t}\right)^{1/\alpha}$$

where α varies with the slope of the fatigue curve of the material (6.5 is typical). By algebra the equation can be solved for the test time (T_t) in terms of the service times (T_s) at various levels. The actual duration the test at a defined level is determined from the sum of all the individual times. Due to questions concerning the current mission profiles and time constraints it was not possible to do this for the HARPOON.

Another factor to consider is the relative magnitude of the acceleration in the three major axis of the missile. Based on accelerometer orientation, the longitudinal acceleration was found to be approximately 2/3's of lateral and vertical components [36]. Finally acceleration was found to vary along the length of the missile. The relative magnitude of the acceleration in relationship to the % of body length from the nose is [36]:

% of Body Length	Relative Amplitude of Acceleration
20%	1.12
53%	1.00
78%	1.33
95%	2.07

Based on this, it would be necessary to increase the overall level of the vibration environment by 1.12 for the WRA's which are located near the nose of the missile.

As part of the development program for the HARPOON measurements were made with the missile mounted on three different aircraft, P-3C Orion (a four engine propeller driven patrol aircraft), S-3A Viking (anti-submarine aircraft powered by two wing mounted jet engines) and an A-7C Corsair (subsonic attack aircraft powered by a single fuselage enclosed jet engine)[37]. The vibration environment was found to be due primarily to the aerodynamic excitation of the missile structure. Below 220 Hz differences between levels for three aircraft indicate that characteristics of propulsion systems are important. In addition it was found that gunfire can increase the overall level by up to 100%. The environments studied in this program included:

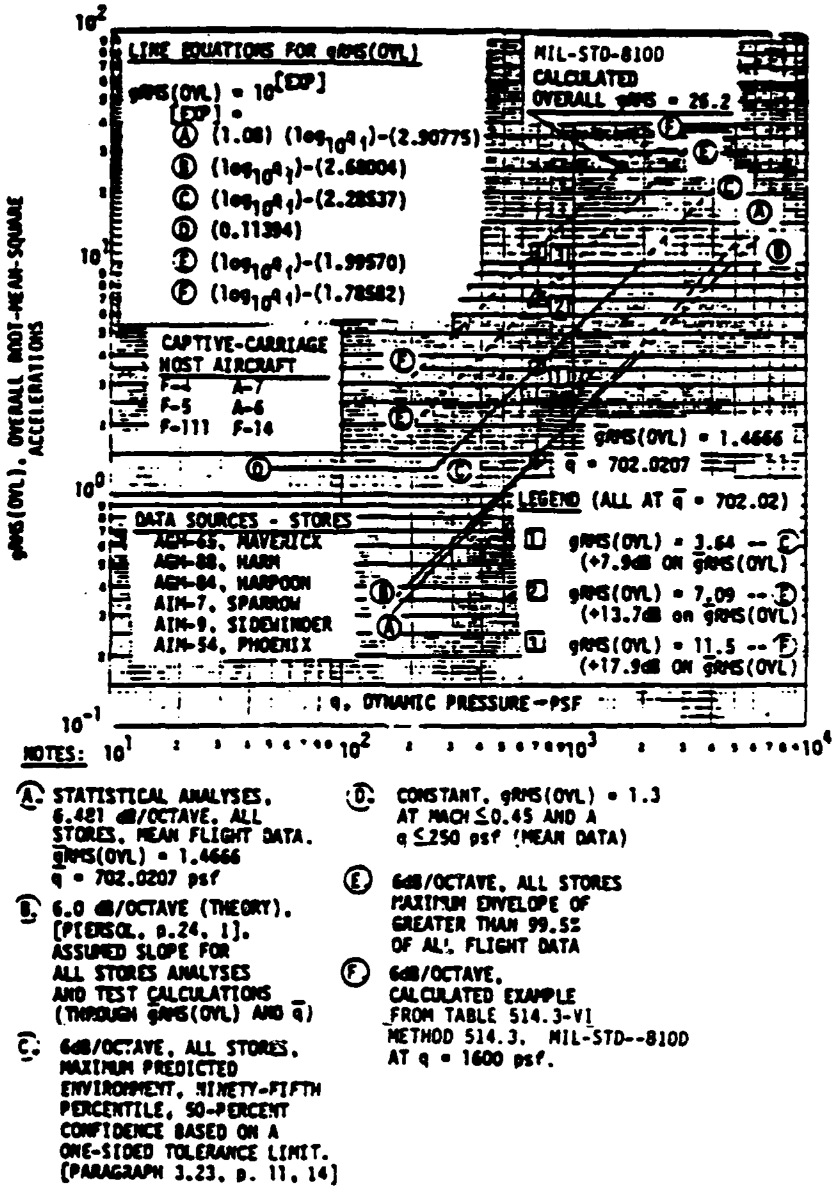


Figure 5-37. Random Vibration Data Measurements and Data Analysis Results from 1839 Flight Data Observations (Reference 36)

Table 5.10 Random Vibration Data, grms (OVL), Level Adjustment Factors for the Maximum Predicted Environment (95th) Percentile with 50-Percent Confidence, Based on One-Side Tolerance Limit) (Reference 26)

CONDITION jth No.	AIR-LAUNCHED MISSILES AND ASSEMBLED EXTERNAL STORES CONDITION OF CONFIGURATION	NUMBER OF DATA MEAS.	(6dB/OCT) q=702.0207 MEAN grms (OVL)i	(6dB/OCT) q=702.0207 MEAN grms1 RATIO TO ALL STORES (grms = 1.4666)	(6dB/OCT)[1] q=702.0207 OVERALL grms1, (95/50) MAX ENVIRONMENT	FACTOR[2] (6dB/OCT) q = 702.0207 RATIO TO (95/50) grms1, grms (OVL)i MAX. ENVIRONMENT	REMARKS[3] (ALL CAPTIVE FLIGHT EXCEPT AS NOTED)
1.	ALL STORES	1839	1.4666	1.00	3.6393	1.00	BASELINE
2.	SINGLE STORE	542	1.2932	0.88	3.2089	0.88	CAPTIVE FLIGHT & FREE FLIGHT
3.	CLUSTER MOUNT	1297	1.8814	1.28	4.6682	1.28	
4.	AGM (ALL)	1203	1.4148	0.96	3.5105	0.96	
5.	SINGLE STORE	816	1.2195	0.83	3.0258	0.83	CAPTIVE FLIGHT & FREE FLIGHT
6.	CLUSTER MOUNT	387	1.8267	1.25	4.5324	1.25	
7.	AAM (ALL)	636	1.5646	1.07	3.8821	1.07	
8.	SINGLE STORE	481	1.4184	0.97	3.5194	0.97	CAPTIVE FLIGHT & FREE FLIGHT
9.	CLUSTER MOUNT	155	2.0181	1.38	5.0073	1.38	

NOTES:

[1] MAXIMUM PREDICTED ENVIRONMENT (RANDOM VIBRATION DATA MEASUREMENTS). NINETY-FIFTH PERCENTILE WITH 50-PERCENT CONFIDENCE, BASED ON ONE-SIDED TOLERANCE LIMIT

[2] EQUATION OF BASELINE (95/50) =

$[grms\ (OVL)]_1 = (10^{[EXP]})_1$

for all $q = (q)_1$

EQUATION FOR CONDITION OF CONFIGURATION $[exp] = [\log_{10} (q)_1 - (2.28537)]$

$[grms\ (OVL)]_i = (FACTOR)_i\ [grms\ (OVL)]_1$

[3] MAXIMUM (q)j FOR grms (OVL) = 1.3 (CONSTANT)

j	q (MIN)	j	q (MIN)	j	q (MIN)
1	250	4	260	7	235
2	284	5	302	8	259
3	195	6	201	9	182

Shock during aircraft catapult launches and arrested landings.

Long term vibration during captive flight.

Short term vibration induced by aircraft gunfire.

Shock loads associated with missile launch forced ejections.

For straight and level captive flight the data indicates that the overall g_{rms} level of response is a linear function of the flight dynamic pressure. Similar results are presented in Reference 38 for the A-6E aircraft, Figure 5.38. This differs with the power relationship given in Reference 36. The following least square regressions results were obtained [37 and 38]:

Aircraft	Equation
A-7C	$g_{rms} = 0.0015 * q$
S-3A	$g_{rms} = 0.0017 * q$
P-3C	$g_{rms} = 0.0021 * q$
A-6E	$g_{rms} = 0.0011 * q$

For a q = 1200 lb/ft^2 this would give an overall level of between 1.32 and 2.52 g_{rms}, which is significantly below the 6.2 g_{rms} obtained utilizing the results of Reference 36. It was not possible to resolve these discrepancies.

The results [37] indicate that the captive flight vibration environment, in terms of the overall levels, of externally carried stores is due primarily to aerodynamic excitation and is relatively independent of the carriage aircraft and mounting location. For sharp turns the vibration levels are substantially greater (in some case an order of magnitude) in the frequency range below 100 hz due to low frequency buffeting. The aft regions of missiles show levels four times those in forward region compared to the factor of 2 given in Reference 36. Below 400 Hz the HARPOON response is higher than Mil-Std-810 requirements but is lower for high frequency region [37]. This is due to the large weight of the missile in relation to those used to generate the Military Standard data. Gunfire increases the level throughout the entire frequency range.

Shock induced loads are a result of several conditions including, aircraft launch and trap on the aircraft carrier, buffeting during maneuvers, firing of other weapons, and ejection of the missile from the pylon. In most cases these loads are very severe and highly dependent on the specific configuration and therefore it is not possible to define generic levels. It becomes necessary to make specific measurements on the configuration in question. Reference 21 deals with the shock environment during ejection launch by aircraft launchers. A series of tests were performed at the Ground Ejection Test Facility at PMTC. Acceleration time histories were measured at a number of locations on the missile. Peak accelerations are summarized in Table 5.11 and range from 6 to 970 g's depending on location and test configuration. The data is also presented in terms of shock response spectra for various location, Figure 5-39. These levels were also compared to the specified test levels, Figure 5-40. For this condition the test shock levels are enveloped by the test requirements.

Shock loads are also produced during the catapult and arrested landing of the aircraft on a carrier. Results from a series of tests of the HARPOON on a A-6E aircraft are given in Reference 38. The peak accelerations as a function of missile station and the shock spectra for the seeker position are given in Figure 5-41 to 5-44. The peak accelerations vary from 3 to 9 g's for the seeker location. Although the levels are significantly below those caused by ejection launch the levels in the low frequency range are significant. The 14 and 30 Hz responses, Figure 5-42, represent the primary modes of the system on the wing. This correlates well with the 12.37 Hz pitch mode given above. The FCE response, missile station 38, has a significant amount of high frequency component due to ringing of the pin-mounted FCE ring.

Acceleration during captive carry is primarily the result of maneuvers of the aircraft. In most cases the resulting stress levels in the components are low when compared to other environments. The functionality of certain components, such as gyros, may be affected by this environment. No specific data is available so the information contained in Mil-Std-810D is assumed to be adequate, Table 5.12. This data includes the acceleration due to catapult launches at a level of 12 g's in the forward direction and 18 g's vertically. These levels envelope the measured levels.

5.3.2 Ship Based

The environmental conditions for the ship based configurations are driven by the design of the ship, its performance characteristics and the sea states to which it is exposed. It is first necessary to define a "typical" mission based on historical data and projections concerning future actions [39]. It was assumed a series of activities, each two weeks long, make up an entire mission. During a typical deployment it was determined that a surface combatant ship would spend:

27% of the time in normal cruising,
35% in combatant activities,
23% in port, and
15% in maintenance, either alongside a tender or in a repair yard.

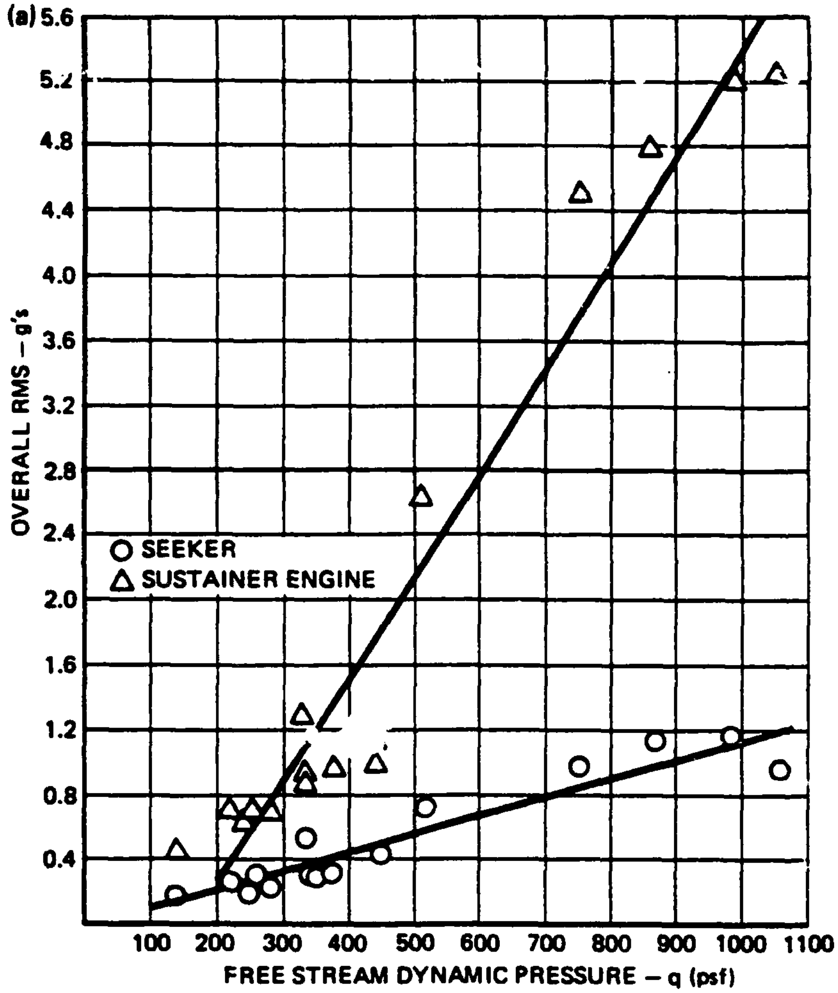


Figure 5-38 G_{rms} versus Dynamic Pressure for A-6E Aircraft (Reference 38)

Table 5.11 Peak Acceleration Levels Measured during Harpoon Ejection Tests. Tests 4 thru 9: Low-force cartridges. Tests 10 and 11: High-force cartridges. (Reference 21)

No.	Location	Direction	Peak acceleration in g's for tests 4 through 11							
			4 MAU-9A/A	5 MAU-9A/A	6 MAU-9A/A	7 Aero-7A-1	8 Aero-7A-1	9 Aero-7A-1	10 Aero-7A-1	11 Aero-7A-1
VS01	Seeker bulkhead	Axial	12	12	12	23	12	13	15	19
VS02	Seeker bulkhead	Lateral	12	12	15	13	10	15	13	14
VS03	Seeker bulkhead	Vertical	10	10	20	18	18	...	30	20
VS04	MGU flight control ring	Axial	...	...	83	...	...	...	...	...
VS05	MGU flight control ring	Lateral	40	50	57	125	85	108	58	27
VS06	MGU flight control ring	Vertical	30	23	19	50	45	60	55	45
VS07	Guidance sect. structure	Axial	24	22	52	45	35	55	45	45
VS08	Guidance sect. structure	Vertical	43	40	64	55	75	65	110	98
VS09	Guidance sect. structure	Lateral	88	65	75	123	87	87	90	100
VS10	Proximity fuze	Axial	52	34	63	...	45	60	75	50
VS11	Proximity fuze	Lateral	...	30	50	...	40	57	63	40
VS12	Proximity fuze	Vertical	90	84	144	...	80	...	160	100
VS13	Forward attach lug	Axial	32	42	38	...	55	55	60	...
VS14	Forward attach lug	Lateral	19	16	36	...	35	35	50	33
VS15	Forward attach lug	Vertical	42	34	78	...	60	60	94	55
VS16	Ejector foot impact	Axial	100	116	248	...	190	250	260	240
VS17	Ejector foot impact	Lateral	140	152	250	...	160	280	450	300
VS18	Ejector foot impact	Vertical	218	176	368	...	500	500	625	650
VS19	T&E sect. structure	Lateral	248	200	576	475	400	600	420	970
VS20	T&E sect. structure	Vertical	205	224	315	350	550	400	660	...
VS21	Aft attach lug	Axial	92	86	118	115	67	137	110	93
VS22	Aft attach lug	Vertical	92	100	150	160	95	142	130	...
VS23	Engine sect. structure	Axial	30	22	42	30	13	33	30	80
VS24	Engine sect. structure	Vertical	52	40	80	97	60	85	65	70
VS25	Engine sect. structure	Lateral	72	46	100	60	...	65	55	50
VS26	Engine sect. structure	Axial	38	35	54	45	20	40	50	...
VS27	Engine sect. structure	Vertical	48	52	80	70	35	90	70	60
VS28	Fuel controller	Vertical	7	9	16	11	6	13	20	...
VS29	Control fin actuator	Axial	33	24	54	30	20	...	40	33
VS30	Control fin actuator	Radial	60	44	108	46	33	57	...	50

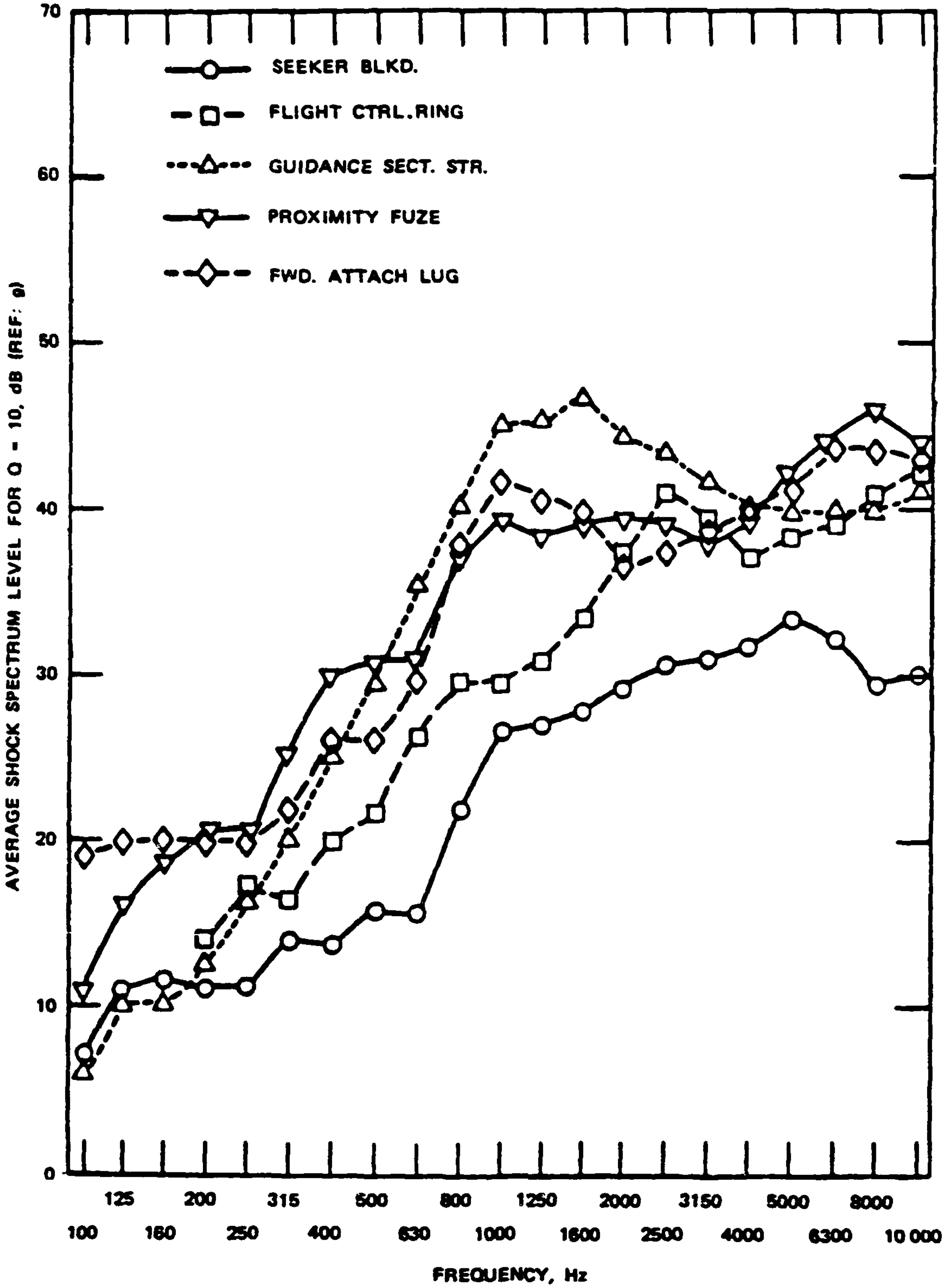


Figure 5-39 Shock Spectra for Q = 10 Averaged Over Three Axes at Various Locations for Ejection (Aero 7A-1 Rack Using High-Force Cartridges). (Reference 21)

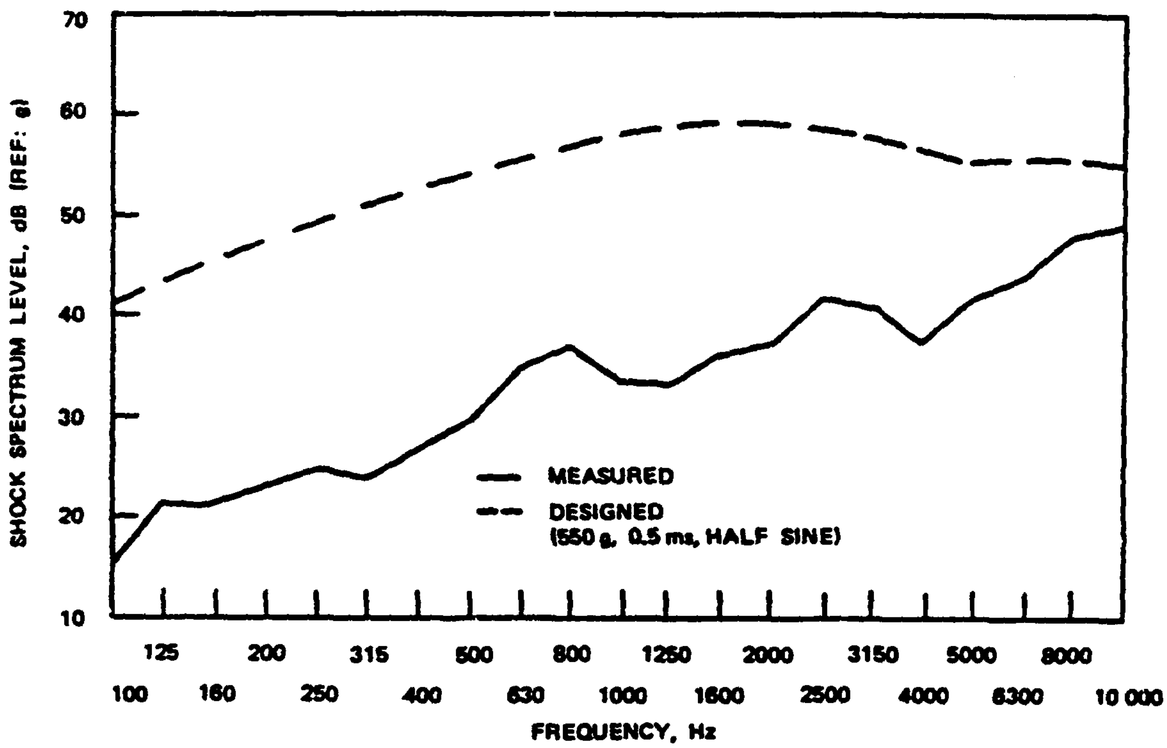


Figure 5-40(a) Comparison of Q = 10 Shock Spectrum Levels and Design Criterion for the Midcourse Guidance Unit (Reference 21)

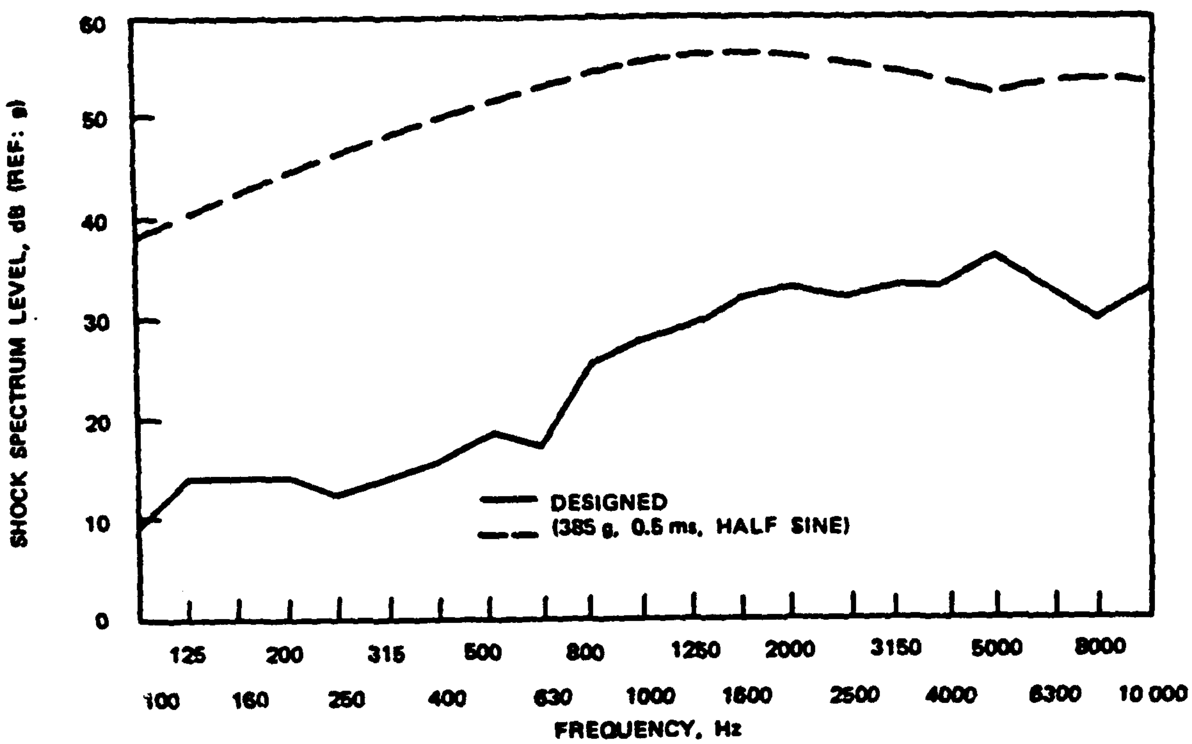
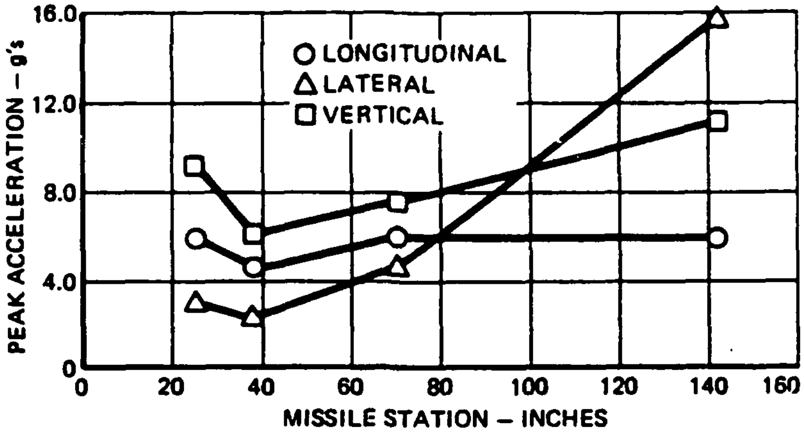
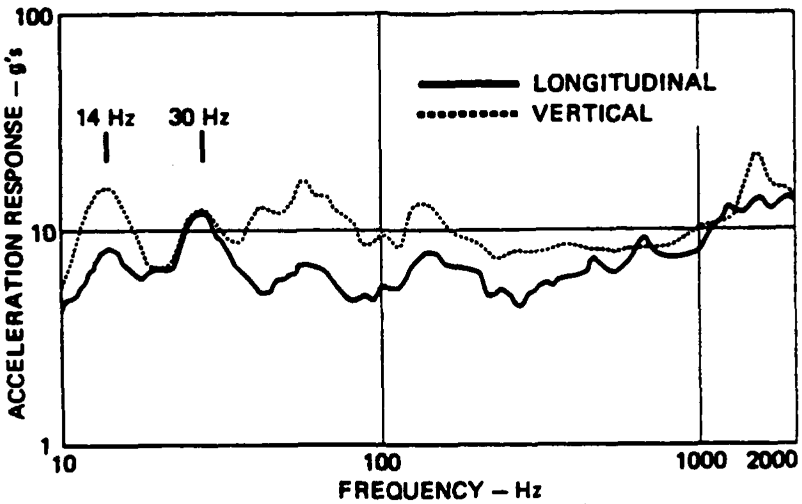


Figure 5-40(b) Comparison of Q = 10 Shock Spectrum Levels and Design Criterion for Seeker (Reference 21)



NOTE: DATA OBTAINED FROM 4 SEPARATE LAUNCHES AS DEFINED IN FIGURE 6

Figure 5-41 Variation of Catapult Launch Peak Acceleration Levels with Missile Location (Reference 38)



NOTE: LATERAL SHOCK SPECTRA NOT GENERATED DUE TO LOW LEVEL.

Figure 5-42 Catapult Launch Shock Spectra for Seeker (Reference 38)

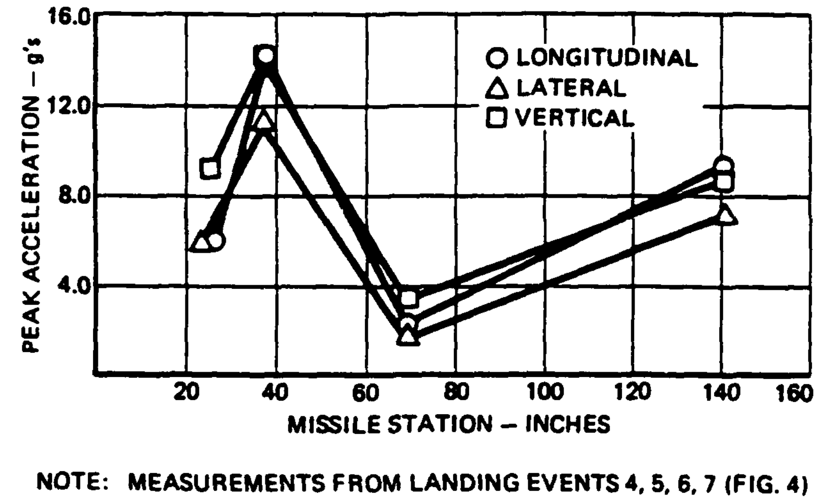


Figure 5-43 Variation of Arrested Landing Peak Acceleration Levels with Missile Location (Reference 38)

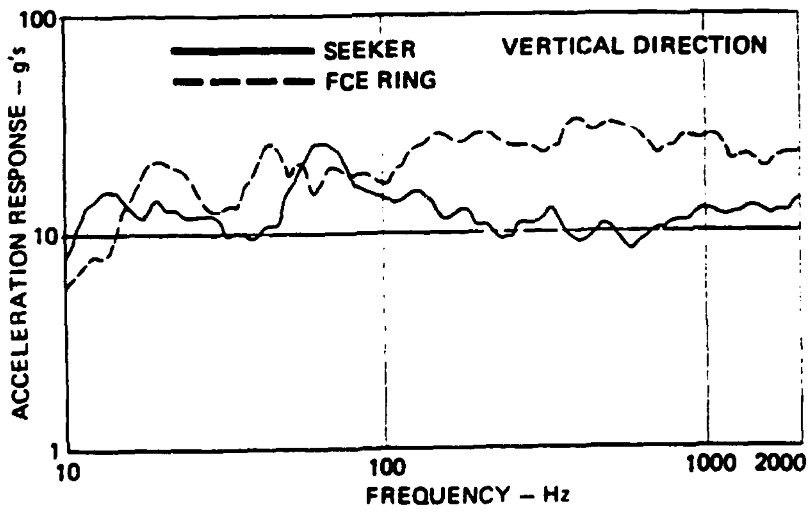


Figure 5-44 Comparison of Arrested Landing Shock Spectra for Seeker and FCE Ring (Reference 38)

Table 5.12 Suggested G Levels for Procedure II - Operational Test (Reference 13)

Vehicle Category		Forward Acceleration A in g's 1/	Test Level: Direction of Vehicle Acceleration (See figure 513.3-1)					
			Fore	Aft	Up	Down	Lateral	
							Left	Right
Aircraft 2/, 3/		2.0	1.0A	3.0A	4.5A	1.5A	2.0A	2.0A
Helicopters		4/	2.0	2.0	7.0	3.0	4.0	4.0
Manned Aerospace Vehicles		6.0 to 12.0 5/	1.0A	0.33A	1.5A	0.5A	0.66A	0.66A
Aircraft Stores	Wing/ Sponson Mounted	2.0	5.0A	5.0A	6.0A	3.25A	3.75A	3.75A
Aircraft Stores	Fuselage Mounted	2.0	3.5A	4.0A	4.5A	2.7A	1.5A	1.5A
Ground-Launched Missiles		6/, 8/	1.1A	0.33A	1.1A' 7/	1.1A' 7/	1.1A' 7/	1.1A' 7/

1/ Levels in this column should be used when forward acceleration is unknown. When the forward acceleration of the vehicle is known, that value shall be used for A.

2/ For carrier-based aircraft, the minimum value to be used for A is 4, representing a basic condition associated with catapult launches.

3/ For attack and fighter aircraft, add pitch, yaw, and roll accelerations as applicable.

4/ For helicopters, forward acceleration is unrelated to acceleration in other directions. Test levels are based on current and near future helicopter design requirements.

5/ When forward acceleration is not known, the high value of the acceleration range should be used.

6/ A is derived from the thrust curve data for maximum firing temperature.

7/ Where A' is the maximum maneuver acceleration.

8/ In some cases, the maximum maneuver acceleration and the maximum longitudinal acceleration will occur at the same time. When this occurs, the test item should be tested with the appropriate factors using the orientation and levels for the maximum (vectorial) acceleration.

Based on historical and projected requirements its was deduced that 18% of "typical" ship missions would occur in colder waters and 82% in temperate to equatorial waters [39]. In this report the environments that were considered are limited to temperature, humidity, vibration and shock.

On board a Navy ship, temperature and humidity environments can be categorized as:

1) Internal, uncontrolled
2) Internal, controlled
3) External to the ship

The first two have extremes that are bounded by the third although the humidity levels can be damaging in the uncontrolled areas. Data for the external condition can be based on Mil-Std-210C and Mil-Std-810D information in terms of variations in temperature and humidity. These are then adjusted to account for operation in both cold and temperate locations. Figure 5-45 is an example of an aggravated temperature-humidity cycle designed to propagate failures quickly. A minimum of ten cycles is recommended for this type of testing.

Work on the TOMAHAWK ABLS during captive carry tests on DD 976 was aimed at measuring temperature extremes [40]. Interior air temperatures consistently reached in excess of 135° F and up to 142° F. The outer skin on missile rocket booster was typically up to 120° F and up to 127° F. These temperatures were for ambient air temperatures of 82 to 86° F. This indicates that there is the potential for a temperature rise of 60° F in relationship to the ambient air temperature. Tests were also run for desert exposure and on a submarine. In these cases the data shows ordnance temperatures approaching 160° F.

There are two basic approaches in developing the definition of the vibration levels for a ship based system. The first, an analytical approach, is based on the Response Amplitude Operator (RAO) technique [41]. Utilizing this procedure the ships response in all six degrees of freedom can be determined, Figure 5-46. It is first necessary to define the nature of the sea conditions in terms of the significant wave height and modal period. From this information it is possible to develop the sea spectrum based an analytical representation, such as that defined by Pierson and Moskowitz [42]. In a parallel effort it is necessary to develop the ship RAO based on a given ship, ship speed and relative wave heading [41]. This operator is then used to modify the sea spectrum to develop a ship response spectrum representing six degrees of freedom motion at the ship center of gravity. This ship motion data is derived for a range of sea conditions representing the range of conditions that may be expected during a mission. It can then be transformed to a specific location on the deck, such as the feet of the LSS. This transformation may be difficult to define for large structures such as the LSS that may have a significant influence on the local compliance of the deck structure. This transformation must also include additional vibration sources such as excitation by the ships propulsion system and other mechanical systems on the ship.

Based on the time scaling procedures defend above, it is then possible to develop test levels and times for a specific location on the ship. This process is workable if the RAO are available for the specific ship in question and the information on the transformation to local deck conditions is available. In most cases approximations must be made at various stages of the process and questions may arise concerning the validity of the results.

The alternative approach is to develop a test program to make measurements at the required locations on the ship while under way. Chalmers [39] has categorized surface combatant ships into four groups based on function:

Category I	PG, PGH, PHM
Category II	CV, CVN
Category III	DD, DDG, FF, FFG, CG
Category IV	LCC, LPA, LHA, LST

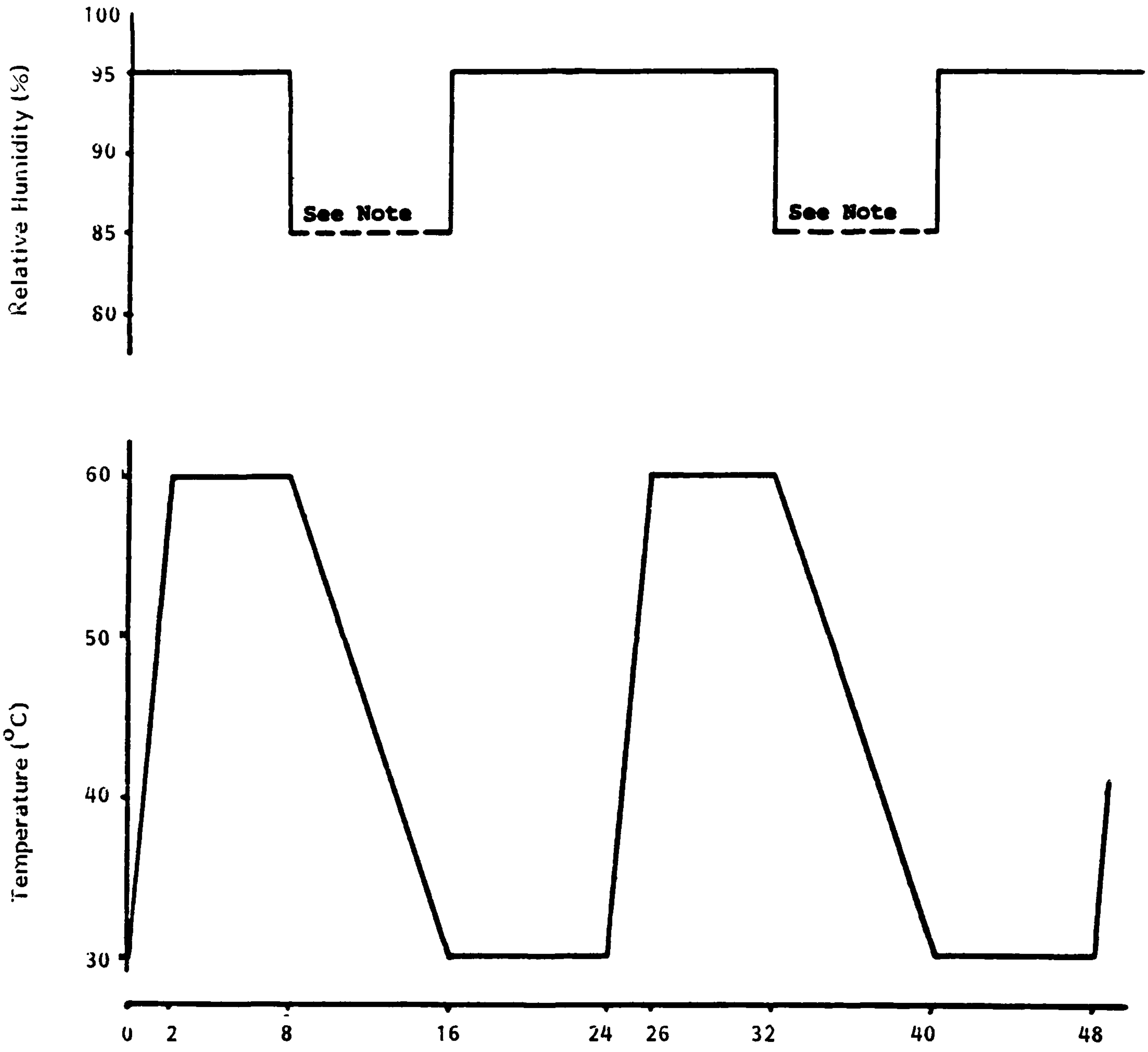
The levels of vibration defined in this measurement program are based primarily on excitation by the engine and propulsion system. Although the screws generate blade passing pulsations which are rich in harmonic content, *ship* structure attenuates frequencies above about 50 hz so that vibrations are predominantly low frequency and varying in amplitude [39]. Field data from Reference 39 was analyzed and reduced to the form of a generic PSD for each of the ship types, Figures 5-47. In all cases the values presented represent mean plus 3σ for input to items and are an envelope of all axes.

The overall g_{rms} for the four categories of ships varies from 0.048 to 0.073 [39]. These represent peak acceleration values up to 0.25 g's based on a normal distribution and a 3σ peak. This is significantly below the peak acceleration utilized in Mil-Std-167, with a peak of over 1 g based on sinusoidal motion. This difference could be in part due to the fact that data was not obtained during severe sea states. This is a major problem with measurement of field service data in that one must wait for the variety of sea states to occur naturally. The data does indicate that the levels in Mil-Std-167 may be high, which becomes important for large structures such as four HARPOONs in CANISTERS on the LSS.

For the HARPOON system there are three basic configurations for which it is necessary to define the dynamic properties of the support structure. They include:

ASROC - Magazine or Launcher Snubbers

TARTAR - Magazine Rack



Note: Relative humidity maintained above 85% during temperature drops.

Figure 5-45 Aggravated Temperature-Humidity Cycles (Reference 13)

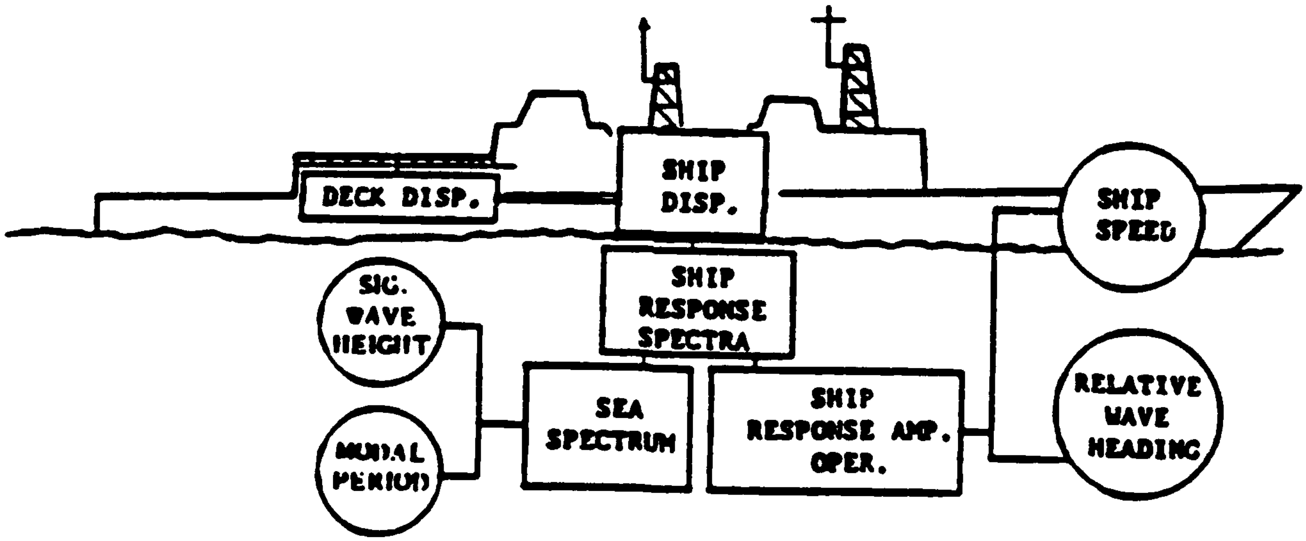


Figure 5-46 Development of Ship Deck Motion Spectrum (Reference 41)

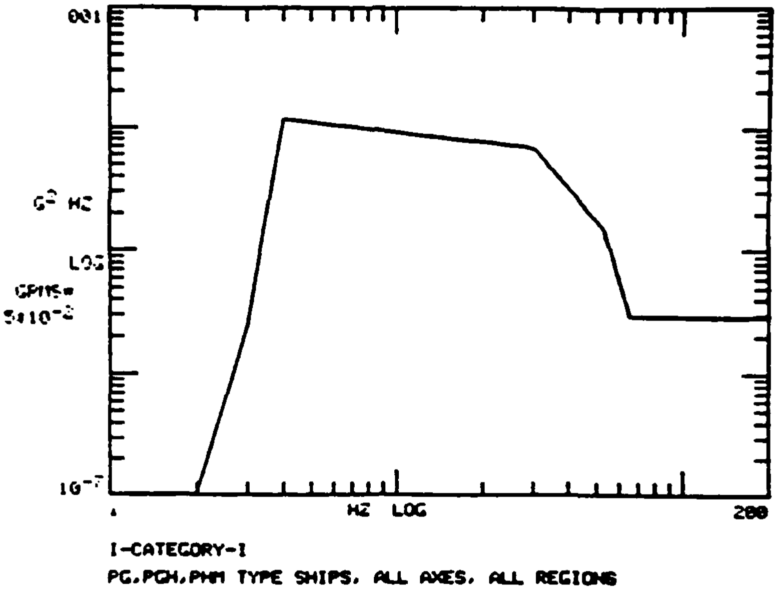


Figure 5-47(a) Vibration Test Spectrum Category I Ships, All Axes, All Regions (Reference 39)

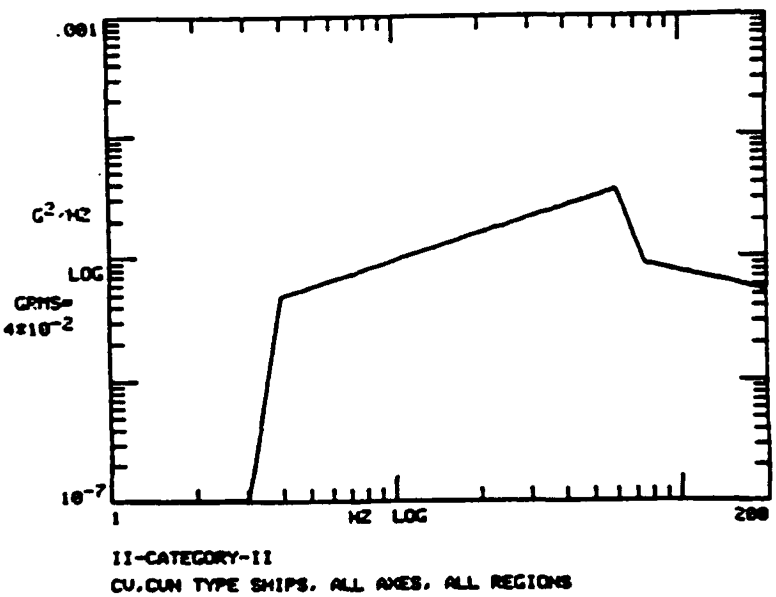


Figure 5-47(b) Vibration Test Spectrum for Category II Ships, All Axes, All Regions (Reference 39)

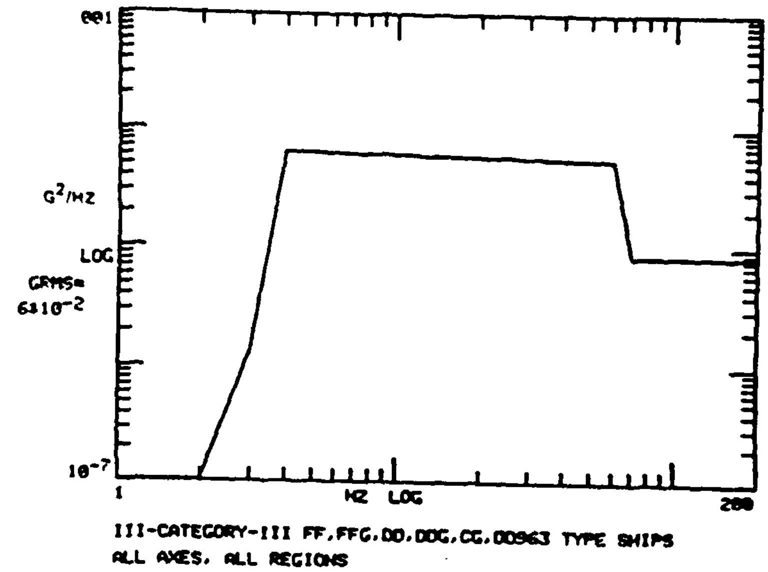


Figure 5-47(c) Vibration Test Spectrum for Category III Ships, All Axes, All Regions (Reference 39)

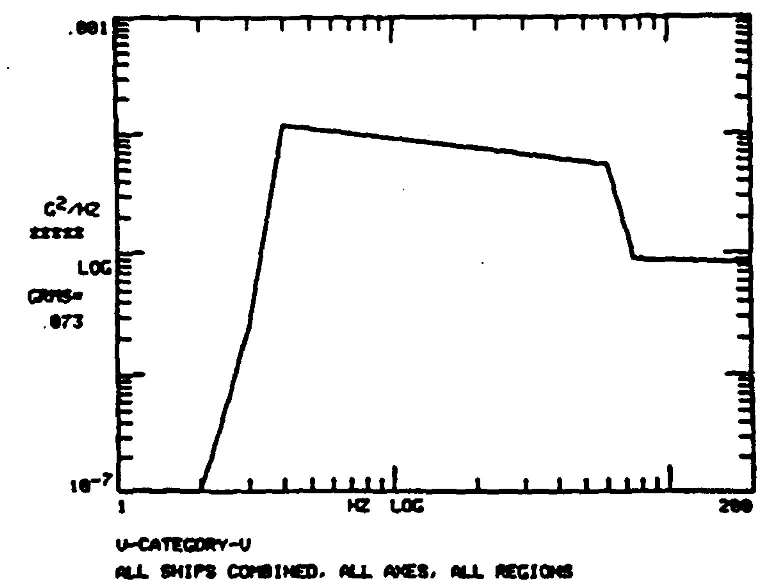


Figure 5-47(d) Vibration Test Spectrum for All Ships Combined (Category V), All Axes, All Regions (Reference 39)

CANISTER - Deck to Launch Support Structure

Lightweight

Grade-B

Thickwalled

The work during this project has been primarily on the definition of the dynamic properties of the HARPOON in the CANISTER. Specific tests have been preformed including shipboard testing on the USS Mississippi [5, 6 and 43], modal testing, on the USS Scott [7], laboratory testing on a single missile and CANISTER at PMTC [8] and vibration testing of a LSS system at Wyle Laboratories [11]. The majority of the results were aimed at looking at the overall system response while the testing at PMTC was to look at specifics of the missile response in the CANISTER and methods of reducing the loads transmitted to the WRA's.

The testing on the USS Mississippi was aimed at looking at the response of the CANISTER system to both normal ship operations in addition adverse conditions such as shock resulting from the firing of 5 inch guns. When considering the vibration under normal operating conditions it should be noted that the measurements onboard the USS Mississippi were taken under calm sea state conditions with no ship propulsion system problems [5]. Constant speed RPM tests were preformed between 30 and 240 RPM in addition to various maneuvers.

Since the vibration measurement data does not appear to be random in nature, caution must be exercised in interpreting any comparison with PSD plots [5]. The environment is basically of a periodic nature with multiple frequency content and varying amplitude. An example of the acceleration response of the seeker as a function of shaft RPM is given in Figure 5-48. From this one can clearly see the presence of a mode of the system at 13 Hz, corresponding to a five plaided propeller at 160 RPM. There appears to be no significant difference in levels for different configurations, Grade-B and Thickwalled CANISTERS [5]. Maneuvering generates the higher response levels and constant RPM tests.

To compare the test requirements, the data on shipboard vibration was presented as a composite or envelope covering all test conditions in each test category for all measurement directions, Figures 5-49 and 5-50 [5]. The measured data was also compared to the equipment design/qualification test levels. The test levels are appreciably higher than measured on the USS Mississippi [5]. This is true for both input to base of LSS and at the WRA's. The peak accelerations at the feet of the LSS, Table 5-13, vary from 0.08 to 0.18 g's peak. These are comparable to the results presented in Reference 39 which give peaks up to 0.25 g's. The peak accelerations at various elevated locations are up to 1.42 g's, Table 5-14. The data indicates that there is amplification from the launcher input (0.18 g's), to the CANISTER frame (0.46 g's) and to the WRA's (0.62 to 1.42 g's).

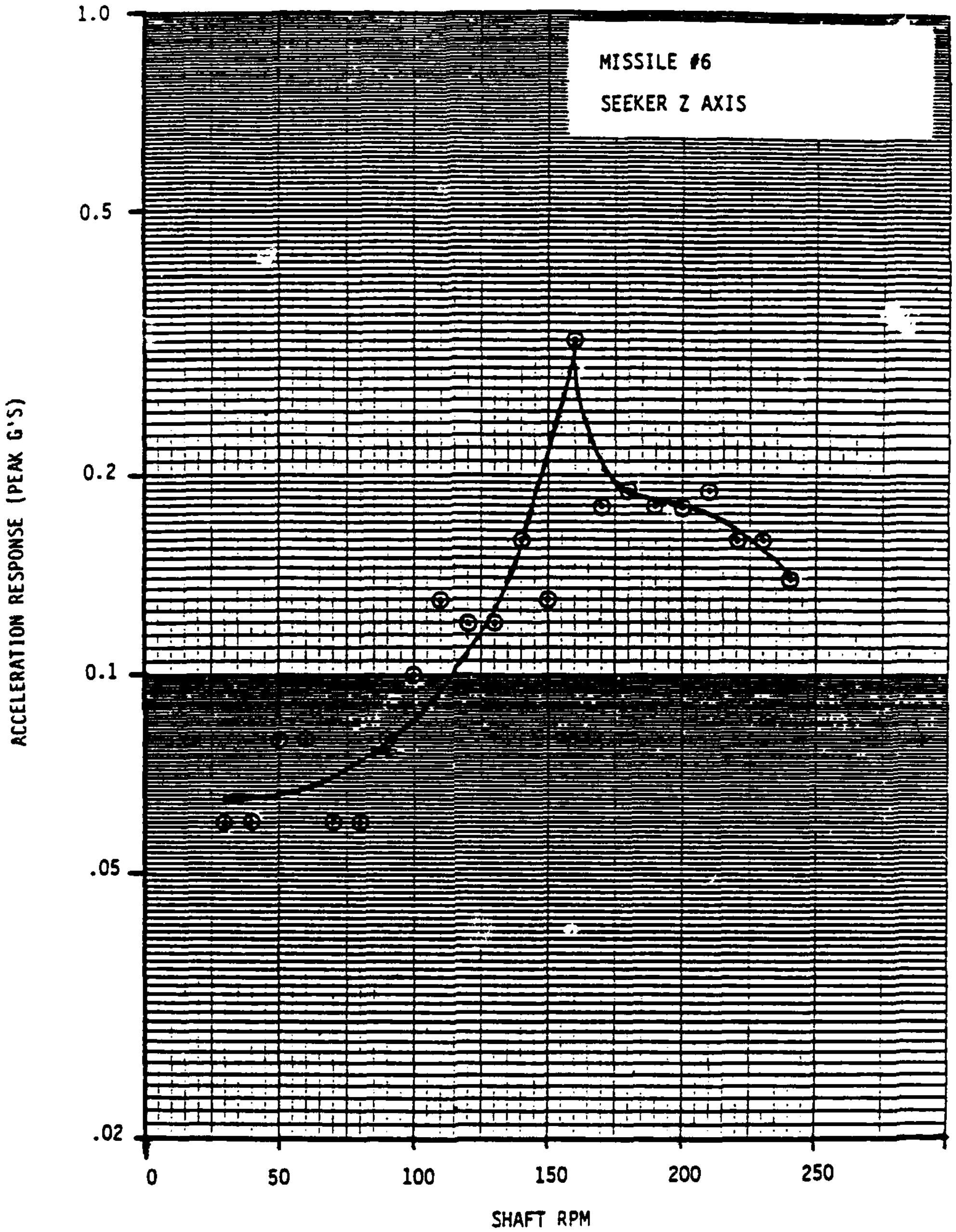


Figure 5-48 Variation of Vibration Response with Shaft RPM (Reference 5)

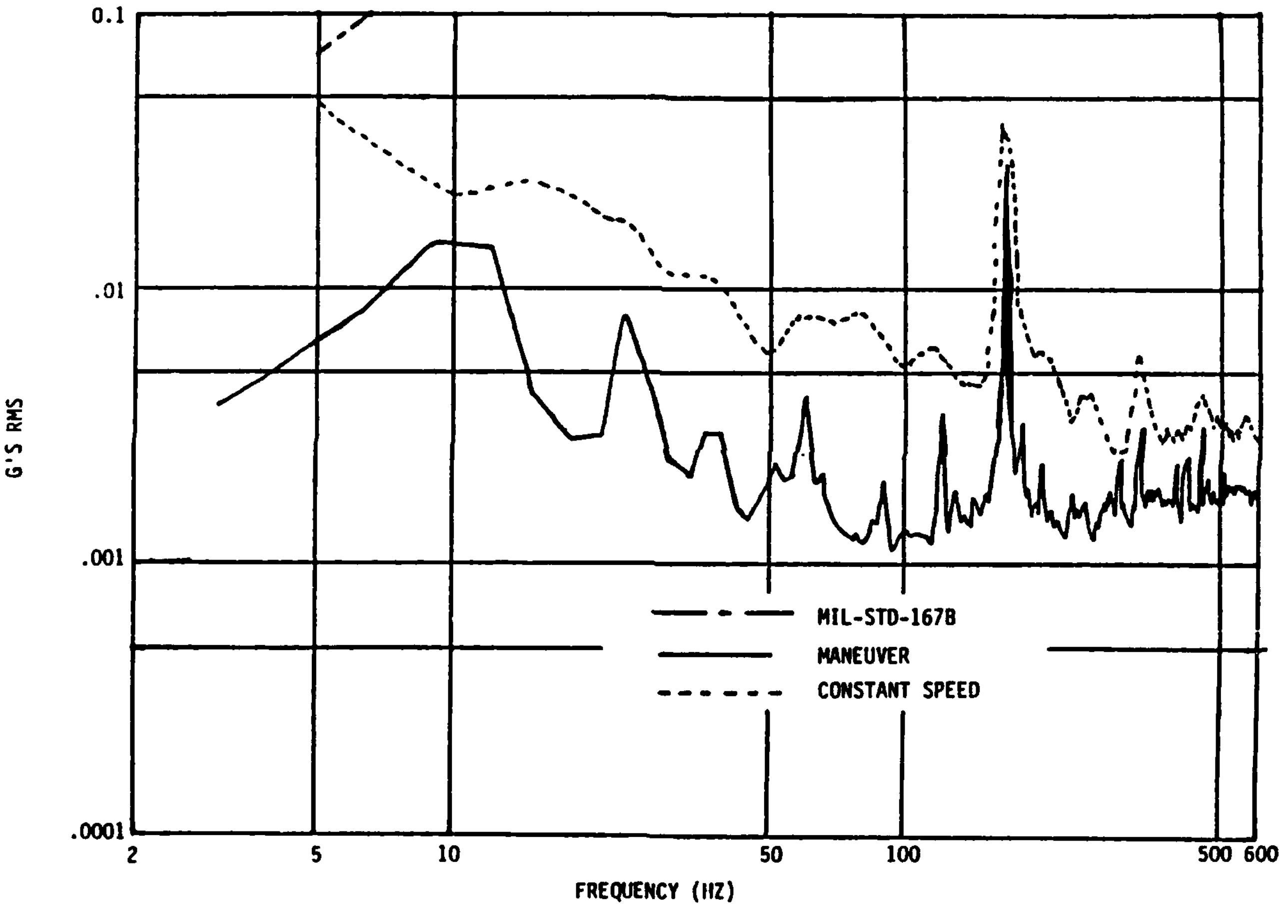


Figure 5-49 Comparison of Mil-Std-167B Vibration Spectrum with Maximum Measured Spectra for Constant Speed and Maneuver at Launch Support Structure/Ship Deck Interface (Reference 5)

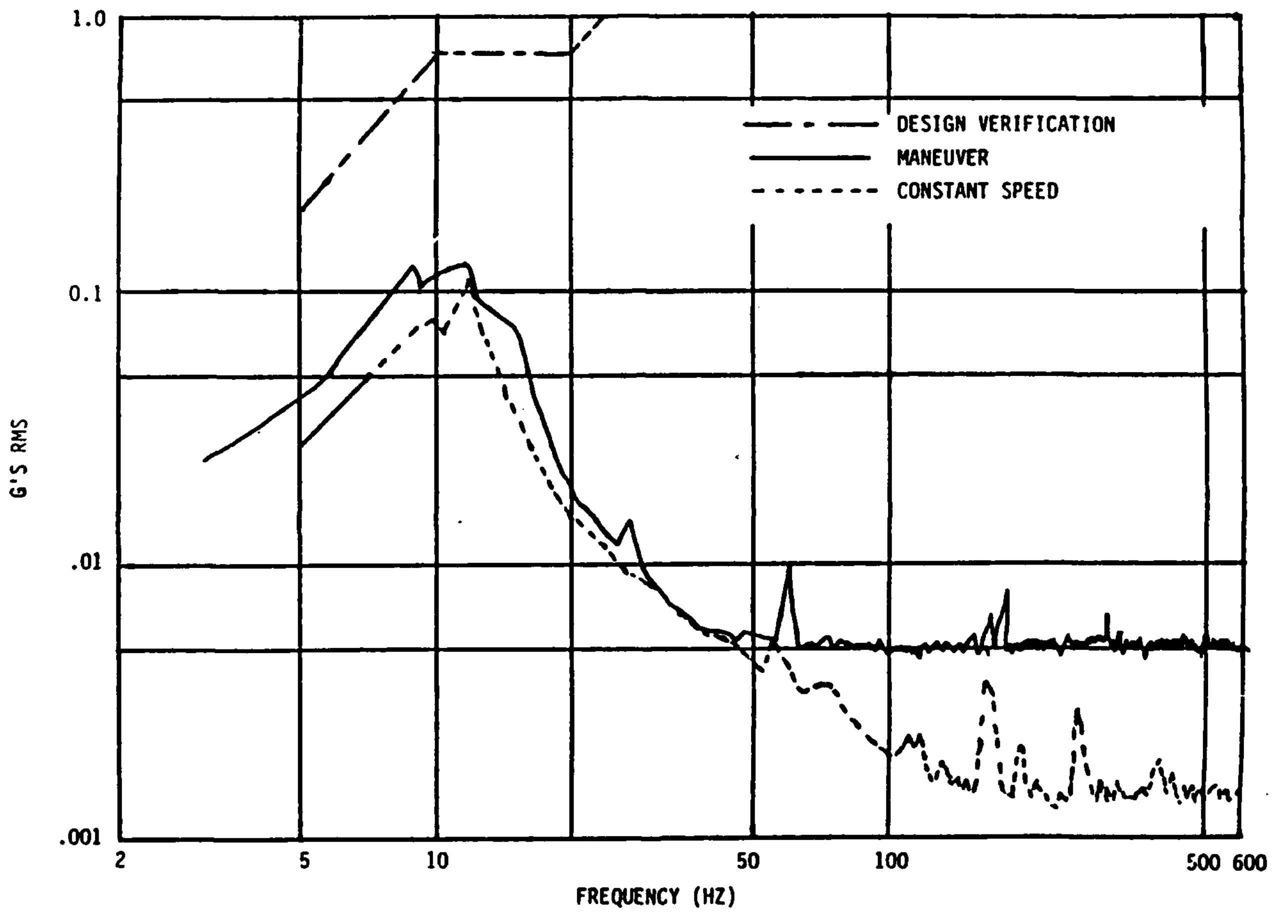


Figure 5-50 Comparison of Seeker Design Verification Test Requirement with Measured Maximum Constant Speed and Maneuver Spectra (Reference 5)

Table 5.13 (a) Launch Support Structure Peak Vibration Acceleration Measurements, Constant Speed and Heading Conditions (Reference 5)

LOCATION	DIRECTION	PEAK G'S
Starboard LSS left forward footpad	X-LAT.	0.10
Starboard LSS left forward footpad	Y-LONG.	0.10
Starboard LSS left forward footpad	Z-VERT.	0.11
Starboard LSS right forward footpad	Z-VERT.	0.08
Starboard LSS left forward footpad	Z-VERT.	0.08

Table 5.13 (b) Launch Support Structure Peak Vibration Acceleration Measurements, Maneuver Conditions (Reference 5)

LOCATION	DIRECTION	PEAK G'S
Starboard LSS left forward footpad	X-LAT.	0.13
Starboard LSS left forward footpad	Y-LONG.	0.10
Starboard LSS left forward footpad	Z-VERT.	0.18
Starboard LSS right forward footpad	Z-VERT.	0.14
Starboard LSS left aft footpad	Z-VERT.	0.09

Table 5.14 Summary of Peak Vibration G Levels (Reference 43)

Location	Constant Speed	Maneuvering
Seeker	0.32	0.62
FCE Ring	0.71	1.42
Sustainer Eng.	0.24	0.61
Missile Shoes	0.27	0.46
Canister Frame	0.23	0.46
Launcher Input	0.13	0.18

Conclusions drawn from the vibration measurements on the USS Mississippi by McDonnell Douglas are that present CANISTER missile fleet return reliability data indicates no evidence that equipment failures are induced by vibration. Shipboard vibration alone would not be anticipated to pose a problem for HARPOON missile equipment [5]. It is noted that the effect of low frequency vibration over time doe not appear to be adequately covered in missile equipment qualification testing. Although the levels of vibration are low it is also important to consider the duration of the loading.

Results from the modal testing on the USS Scott [7] and the vibration testing at Wyle Laboratories [11] are very similar. Both of these tests show a significant side to side motion of the LSS at approximately 13 Hz. This corresponds directly to the results of the USS Mississippi testing verifying that this response is a system dynamic mode. Additional details of some of the higher order modes were obtained from this testing. This information can be used in developing the appropriate transfer functions to modify deck level vibration to derive input levels into the WRA's.

The results of the laboratory testing at PMTC indicate the presence of significant response of the missile within the canister, Figure 5-51. This amplification must be considered when developing test response spectra for the WRA's. The method of positioning the missile within the CANISTER, on the rails and held in place with the studs and shoes can lead to significant high frequency rattling under vibration input due to the metal to metal contact at these locations.

Shock is the result of direct hits during hostilities, underwater blasts from near misses, and the shock from firing ones own weapons including adjacent CANISTERS or cells. The first two, although of a high level, are sufficiently rare that they can be ignored in most cases. Qualification to those levels are accomplished during Mil-S-901C tests. Recoil from the firing of the guns appears not to be a problem, but the muzzle blast has the potential to cause damage [39]. This is also true considering the firing of adjacent cells.

During the test aboard the USS Mississippi, a 5 inch gun was fired at a variety of train and elevation angles with both standard and high velocity rounds, to get an indication of the loading due to these conditions. In general, the peak g levels for the high fragmentation round test conditions exceed the corresponding measurements for the standard rounds. In each case the maximum shock spectrum occurs in the lateral axes of the missile [5]. Maximum gunfire missile response was at gun train/elevation angle extremes. The gun elevation influences response primarily when the gun is trained to the same side as the guidance section. Clipping was present in a number of channels which made analysis of the data difficult.

The pressure pulse producing the response is attenuated with distance. In addition to the distance consideration, reflected pressure off of ship structure is effected by gun position and likely to have a significant influence on missile response [5]. For the USS Mississippi testing, the missile nearest bulkhead experiences highest response. The response of the system to the pressure pulse consists of a number of cycles. Therefore, the damping used will effect the results in calculating the shock spectra levels.

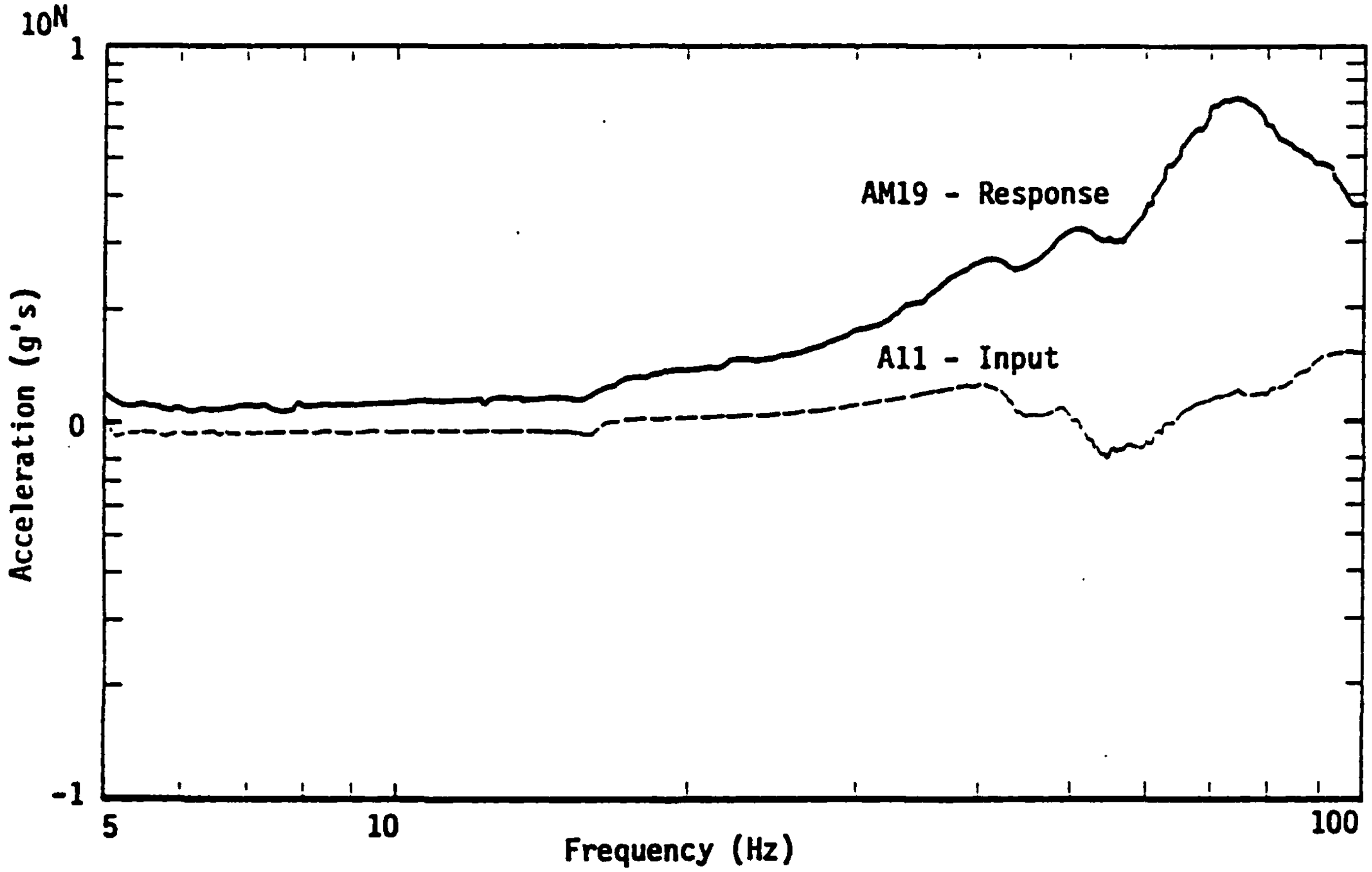


Figure 5-51 Response at Seeker Bulkhead, Original Hardware, Tracking Filter Data, Run No. 14 (Reference 8)

For each of the locations a composite shock spectrum was developed from individual shock spectra relating the many gunfire test conditions and the three measurement directions. Peak accelerations for a number of locations are summarized in Table 5.15. Note that all spectra used for comparison are based on 5% damping and that some of the data was derived from clipped acceleration time histories. The Seeker shock spectra levels are considerably higher than qualification test requirement above 1700 Hz, Figure 5-52. The FCE ring and guidance section response also exceeds qualification test levels.

Table 5.15 Summary of Gunfire Response Measurements (Reference 5)

Location	Standard Rounds	High Velocity Rounds
Seeker	65 g's	65+ g's clipped
FCE Ring	47 g's	65+ g's clipped
Engine Ring	17 g's	33 g's
Pressure	3.2 psi	4.3 psi

The seeker gunfire shock response spectra presented in Figure 5-52 exceeds the seeker qualification test environment for both the standard and high fragmentation rounds. The shock spectra presented suggests that the majority of the gunfire response environment is concentrated in the high frequency region above 1500 hz. In general typical equipment is insensitive to shock response at such high frequencies [5]. It is therefore McDonnel Douglas's opinion that the gunfire levels alone are unlikely to cause a problem. However the cumulative effects on repeated gunfire response or the effects combined with other environments are difficult to predict. It is recommended that the gunfire measurement data be used to update design/qualification requirements for guidance section missile equipment. In any future qualification testing of equipment gunfire shock environment simulation should be included [5].

5.3.3 Submarine Based

Data for environmental conditions associated with submarines is difficult to come by. Because of the low failure rate for this system it was not necessary to spend any effort in looking at redefining the levels associated with this platform.

5.4 Flight Environment

Flight environments will be similar for all platforms. The only differences will be the booster phase for all but the air based and the water phase for the submarine based. It is assumed XAS-2381 is appropriate in this area with the flight conditions listed in Table 5.9. The one question that arises from the information is associated with the defined acceleration levels. It appears that the levels for the vertical and lateral components are switched in some cases.

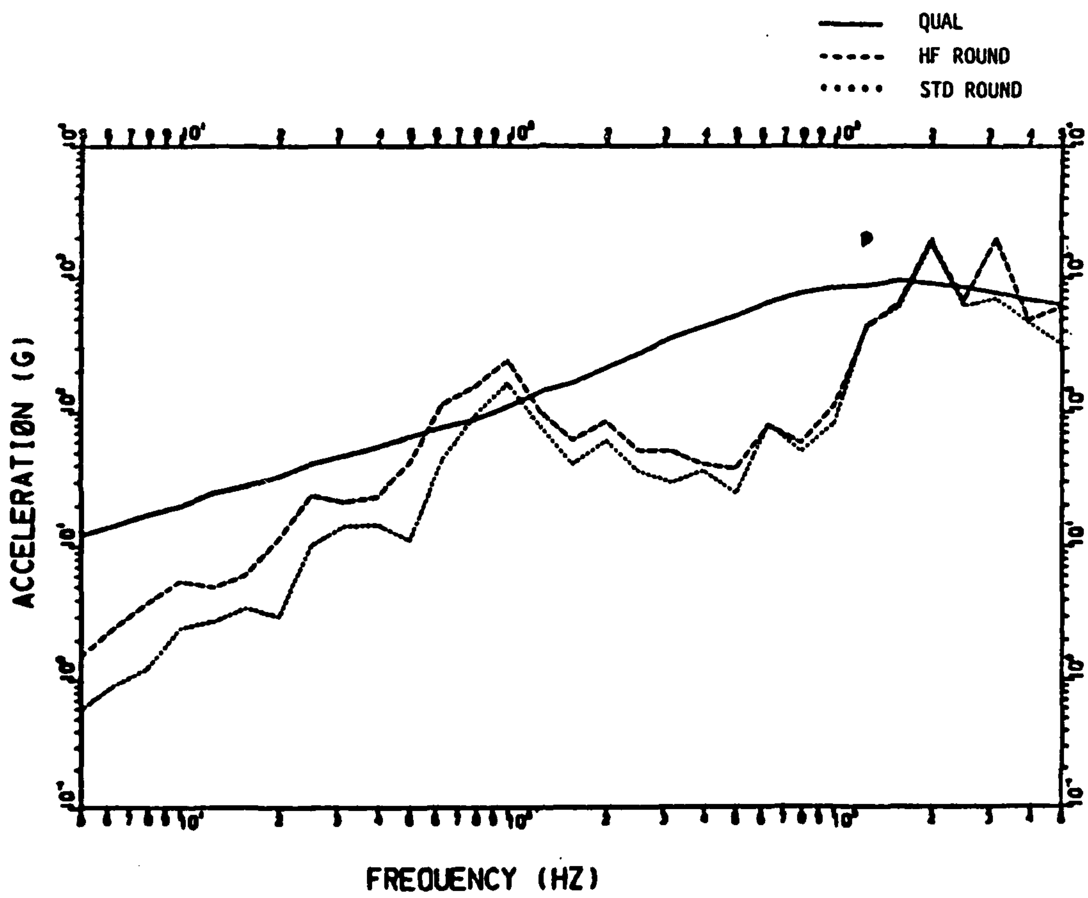


Figure 5-52 Comparison of Seeker Qual. Shock Spectrum with Measured HF and STD Round Gunfire Shock Response (Reference 5)

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